Deliverable D2: State-of play analysis for the development of the master's study programme "European Master of Particle physics and Accelerator Technologies for Research and Industry" (EMPATRI)

Introduction

High-energy particle physics (HEP) is a field of science dedicated to the study of the fundamental constituents of our Universe, the elementary particles, and the fundamental forces that govern their behaviour. Experimental HEP is a highly sophisticated field of scientific research, requiring extremely complex technological solutions. HEP encompasses a vast breadth of topics, from physics data analysis to detector and accelerator technology development, to development of electronic readout and computing technologies. As concluded by the European Committee for Future Accelerators (ECFA)[1] in "The 2021 ECFA Detector Research and Development Roadmap" document[2]: *"Particle physics experiments demand technology well beyond the state-of-the-art, with ever increasing complexity. Establishing novel technologies requires decades from conception to application. The detector development programme of particle physics experiments must be accompanied by a well-balanced training programme aimed at preparing the next generations of detector developers required by the field and by industry."* The consortium of higher-education institutions (HEIs) and the study programme designed through this Erasmus Mundus Design Measures (EMDM) project, "European Master of Particle physics and Accelerator Technologies for Research and Industry" (EMPATRI) seeks to contribute significantly to the training of future experts in particle physics and related instrumentation.

At the time of writing, all three Baltic states are associate member states of the European Organisation for Nuclear Research (CERN), which is also known as the European Laboratory for Particle Physics, with Estonia in the process of ratifying its accession to the status of full member. CERN in the world's leading laboratory for HEP and is the home of the world's most powerful particle collider – the Large Hadron Collider (LHC). LHC, in turn, hosts the most grandiose and complex particle physics experiments created to-date: ATLAS, CMS, ALICE and LHCb. All three Baltic states participate in the physics programme of the CMS collaboration. Besides this, Latvia is involved in the AEgIS and MEDICIS collaborations, while Estonia is contributing also to the CLOUD and AMBER collaborations.

Higher education in physics in the Baltic states.

The Baltic states are home to a multitude of high-quality HEIs offering higher education opportunities of a standard comparable to the more well-known universities of Western Europe and North America. This standard of higher education extends to the fields of natural and physical sciences. Study opportunities in physics are available at all levels of higher education.

At bachelor's level, comprehensive study programmes in physics are offered by three major universities. The **University of Tartu** offers a 3-year, 180 ECTS study programme **"Physics,**

[1] https://ecfa.web.cern.ch/.

[2] https://cds.cern.ch/record/2784893/files/ECFA%20Detector%20R&D%20Roadmap.pdf.

Chemistry and Materials Science", where students specialise in one of the three degree directions during their studies. The degree awarded for the completion of this programme is *Bachelor of Science*, and the language of instruction for this programme is Estonian. The **University of Latvia** offers a 3-year, 180 ECTS bachelor's programme **"Physics"**, with the language of instruction being Latvian and the degree awarded - *Bachelor of Natural Sciences in Physics*. **Vilnius University** offers a 4-year, 240 ECTS programme **"Physics",** with the qualification attained after completing the programme being *Bachelor of Physical Sciences*, as well as a more specialised programme **"High-Tech Physics and Business"**, also comprising four years of study and 240 ECTS and awarding the qualification of *Bachelor of Physical Sciences*.

Additionally, a few more specialised bachelor's degree programmes connected to the field of physics are available in Lithuania. **Kaunas University of Technology** offers two specialised bachelor programmes, **"Engineering physics"** and **"Physics of materials and nanotechnology"**. Both of these degree programmes comprise 4 years of study and 240 ECTS and are offered both in Lithuanian and English, with the graduates of these programmes achieving the qualification of *Bachelor of Physical Sciences* and *Bachelor of Technology and Physical Sciences*, respectively. Finally, **Vilnius University** offers study programmes **"Light Engineering"** and **"Electronics and telecommunication technologies"**, which are 4-year, 240 ECTS programmes with English as the language of instruction. The degree awarded for these programmes are *Bachelor of Technological Sciences* and *Bachelor of Engineering Sciences*, respectively.

At the master's level, comprehensive and specialised physics degrees are offered by four universities. The **University of Tartu** offers a comprehensive 2-year, 120 ECTS programme **"Physics"**, instructed in Estonian, and a 2-year, 120 ECTS programme **"Materials Science and Technology"**, instructed in English. Completion of both of these programmes result in the award of the degree of *Master of Physical Sciences*. **The University of Latvia** offers a comprehensive 2-year, 120 ECTS master's degree programme **"Physics"**, available both in Latvian and English. Completion of this programme results in the award of the degree of *Master of Natural Sciences in Physics*. **Vilnius University** offers four specialised master's programmes relevant to this document, all comprising 120 ECTS over two years of study. Three of these, "**Theoretical physics and astrophysics**", **"Laser physics and optical technologies"** and **"Laser technology"** are offered in Lithuanian and English, with the former two awarding the degree of *Master of Physical Sciences* and the lattermost awarding the degree of *Master of Technological Sciences.* The fourth programme, offered in English, is **"Photonics and Nanotechnology"**. Completion of this programme results in the award of the degree of *Master of Technological Sciences*. Finally, **Kaunas University of Technology** offers the **"Physics of materials"** master's programme, comprising 120 ECTS across two years of study. This programme is offered in Lithuanian and English and results in the award of the degree of *Master of Physical Sciences*. It should also be noted that the programme **"Laser physics and optical technologies"** provides the currently only opportunity to study in an Erasmus Mundus Joint Master's (EMJM) programme in the field of physics in the Baltic states as part of the **Europhotonics – International Master of Photonics**[3] study programme.

The opportunity to obtain a doctoral degree in physics (PhD) is currently offered by six HEIs in the Baltics. In Estonia, a PhD in physics can be obtained at the **University of Tartu** and the **Tallinn**

[3] www.europhotonics.org.

University of Technology (in conjunction with the National Institute of Chemical Physics and Biophysics). In Latvia, a PhD in most of the fields of physics is offered by the **University of Latvia**, with the **Riga Technical University** also offering an opportunity to obtain a PhD in particle physics. In Lithuania, **Vilnius University** offers doctoral studies allowing to obtain a PhD in physics in a broad range of physics fields, whilst **Kaunas University of Technology** offers the opportunity to obtain a doctoral degree in physics focusing on materials science aspects. Additionally, **Kaunas University of Technology** offers the opportunity to obtain the PhD in Physics in a joint programme with the University of Southern Denmark. Finally, it must be highlighted, that the currently only doctoral study programme in the Baltic states dedicated specifically to the particle physics and particle physics instrumentation, **"Particle physics and accelerator technologies"**, is available in Latvia, offered jointly by the Riga Technical University and the **University of Latvia**. All this demonstrates the solid base of competencies, knowledge, and skills in the three Baltic states at all levels of education, to allow for offering high-quality master's level education in physics. Additionally, it clearly demonstrates that, although the teaching competencies in both physics and technology are available in the region, no master's level study programme focusing on particle physics and detector development, accelerator physics and technologies, and particle physics instrumentation on a broader level currently exists in the region. Furthermore, the existence of PhD study opportunities in all three of the Baltic states, in particular, the existence of the doctoral study programme "Particle physics and accelerator technologies" in Latvia, clearly demonstrates the need for a master's degree programme focusing on the aspects of particle physics instrumentation in the region to provide a bridge between the comprehensive physics programmes at the bachelor's level and the requirements of doctoral studies with a focus on particle physics. The EMPATRI programme would provide and ideal complement to the existing higher-education ecosystem in the Baltic states.

Particle physics and particle physics instrumentation research ecosystem in the Baltic states.

At present, the main HEP experiment of choice for all three Baltic States is the CMS (Compact Muon Solenoid) experiment at the LHC. Research clusters at the **National Institute of Chemical Physics and Biophysics** and the **Tallinn University of Technology (Estonia),** at **Riga Technical University** and the **University of Latvia** (Latvia), and at **Vilnius University** (Lithuania) are members of the CMS collaboration. Besides working on the various HEP analysis topics at CMS, HEIs from all three states are also deeply involved in the instrumentation and detector development tasks at CMS. **Estonian groups** participate in the operation and maintenance tasks for the muon drift-tube (DT) detectors, the development of the CMS triggering algorithms, the development of the *Beam, Radiation, Instrumentation and Luminosity* (BRIL) instruments, including the development of the *application specific integrated circuit* (ASIC) for the *Fast Beam Condition Monitor* (FBCM) detector, and the maintenance of the CMS computer grid. The **Latvian CMS consortium** has significant involvement in the development of the new timing layer for the Phase-2 upgrade of the CMS experiment, the Minimum Ionising Particle (MIP) Timing Detector (MTD), with leading roles in the assembly of the detector, detector control and safety system (DCS and DSS) development, material studies of the crystal scintillators used in the detector, and the integration of detector description in the overall CMS software framework. Lithuanian researchers are likewise involved in the studies of the properties of the crystal scintillator material used in the MTD barrel timing layer. Additionally, Lithuanian CMS group also works on the development of

the data acquisition (DAQ) systems and on the characterization of the silicon pixel tracking detector components for the Phase-2 upgrade.

In addition to CMS, researchers from all three countries are involved in the Crystal Clear Collaboration (CCC), aimed at studies and crystal scintillator material and the development of the next generation of scintillating crystal detectors. The **University of Tartu** participates in the CLOUD (Cosmics Leaving Outdoor Droplets) experiment, based on the Proton Synchrotron (PS) at CERN, and in the AMBER (Apparatus for Meson and Baryon Experimental Research) experiment, connected to the Super Proton Synchrotron (SPS). Moreover, the research cluster at the **Vilnius University** have recently been involved in physics studies at the LHCb experiment at CERN.

Furthermore, research clusters at the Baltic HEIs are actively involved in the particle physics instrumentation, accelerator physics and accelerator technologies research in collaboration with CERN. **Tallinn University of Technology**, the **University of Tartu** and **Riga Technical University** are members of the Future Circular Collider (FCC) collaboration; **Riga Technical University** has joined the International Muon Collider Collaboration (IMCC). In addition, **Tallinn University of Technology**, **Riga Technical University**, **Vilnius University (via the Center for Physical Sciences and Technology)** and **Vytautas Magnus University** are participants in the CERN-led Innovation Fostering in the Accelerator Science and Technology (I.FAST) project.

Finally, the Baltic states are home to several industrial partners, where specialists in particle physics instrumentation are highly sought after. Specific examples include **GScan (Estonia)**, a company specialising in 3D scanning using the muon tomography imaging technologies, and **Baltic Scientific Instruments (Latvia)**, specialising in the development of semiconductor-based radiation detectors for industrial purposes. All this demonstrates the broad range of available research avenues for master's level students undertaking a degree focused on particle physics and particle physics instrumentation in the Baltic states. Furthermore, it also demonstrates the potential employment pathways in the Baltic states, both in academic research and industry. Finally, it supports the conclusions drawn from the discussion of the previous section of this document, justifying the need for a master's level study programme focusing on particle physics instrumentation, such as EMPATRI, to provide a pipeline of highly trained researchers for the research clusters in the Baltics.

Higher education and training in particle physics instrumentation in Europe.

There are a plethora of bachelor's, master's, and doctoral level degree programmes in Europe offering both comprehensive physics study programmes, and programmes focused on either particle physics materials science, or engineering topics applicable to particle physics instrumentation. However, there is a limited number of educational opportunities tailored for particle physics instrumentation, accelerator physics and technologies, such as the EMPATRI study programme designed through this EMDM project. This gap in education is mostly covered by various intensive short-term schools, usually organised by the major physics laboratories, such as

CERN. These include ESIPSAP[4], CAS[5], JUAS[6], and more. Such schools are excellent educational opportunities and their importance, impact, and role in furthering the fields of particle and accelerator physics and instrumentation should not be dismissed or diminished. However, formal education in the form of a master's degree would be a highly complementary educational avenue for these fields of research. As far as discernible, at the time of writing, only one comparable master's study programme exists, which is also implemented in the EMJMD framework as "International Master on Advanced methods in Particle Physics"[7](IMAPP). IMAPP is an excellent master's programme implemented by the University of Clermont Auvergne in Clermont-Ferrand (France), the TU Dortmund (Germany), and the University of Bologna (Italy). It retains a deep focus on the experimental particle physics and particle physics theory; however, it also has a secondary focus on the instrumentation topics. EMPATRI seeks to be highly complementary to IMAPP, having a deep focus on particle physics instrumentation and technologies, with a secondary focus on experimental particle physics and particle physics theory.

It must be additionally and clearly stated, that ECFA have defined a development of multiple pan-European master's programmes focused on particle physics instrumentation, as one of the most important next stages for retention and further solidification of the European leadership in the field of fundamental HEP. The proposed EMPATRI programme has been discussed with the leaders of the Task Force 9 of "The 2021 ECFA Detector Research and Development Roadmap", focused on the development of the necessary training opportunities in Europe, and has received a full endorsement from the committee.

[4] https://indico.cern.ch/category/5389/.

[5] https://cas.web.cern.ch/.

[6] https://www.esi-archamps.eu/juas-presentation/.

[7] https://imapp.eu/.