PROCEEDINGS OF SCIENCE

IPPOG and spin-offs from particle and nuclear physics

Panagiota Foka*

GSI Helmholzzentrum für Schwerionenforschung
Planckstraße 1, 64291 Darmstadt, Germany
E-mail: yiota.foka@cern.ch

While the mandate of particle physics research institutes is fundamental research, the developed technologies find applications for the benefit of society. With the aim to highlight their impact on medical applications and, in particular, on cancer treatment, the Particle Therapy MasterClass (PTMC) package was developed and integrated into the International MasterClass 2021 (IMC) online programme, attracting immediately some 37 institutes from 20 countries and more than 1500 students. The PTMC, focusing on the topic of cancer treatment, a particularly sensitive topic, is becoming increasingly popular, attracting the interest of students and tutors alike. The main idea is to show that (a) fundamental properties of particle interactions with matter, which are used to detect them in physics experiments, are also the basis for treating cancer tumours; and (b) the same accelerator technologies are used in both research laboratories and therapy centres. Ultimately students are shown "what physics has to do with medicine" and what are the various possibilities that physics and STEM studies may open up for job opportunities in fields that there is lack of expert personnel. The PTMC is indeed put forward, as a tangible example of benefits to society from fundamental research by IPPOG, the International Particle Physics Outreach Group, complementing is main mission to bring the excitement of particle physics to the public and especially to the young generation. Another example along these lines is the effort of the IPPOG working group "Outreach of applications for society". Its objective is to create a collection of short stories, covering a wide spectrum of spin-offs from particle and nuclear physics fields. The ultimate goal is to connect fundamental research to everyday life and provide a practical communication tool for the science outreach community.

The XVIth Quark Confinement and the Hadron Spectrum Conference (QCHSC24)
19-24 August, 2024
Cairns Convention Centre, Cairns, Queensland, Australia

*Speaker

ISSN 1824-8039 . Published by SISSA Medialab.

PoS(QCHSC24)026

1. International Particle Physics Outreach Group

The International Particle Physics Outreach Group (IPPOG) is a network of scientists, science educators and communication specialists working across the globe in science education and public engagement for fundamental physics research. The IPPOG experts come from prominent national or international professional physics centres, universities, societies and laboratories engaged in particle and nuclear physics research as well as from major particle physics experiments. The diversity of their cultural and educational backgrounds brings a large and important variety of skills which permit for the effective development of outreach activities with maximal impact. The IPPOG members represent links to several national-level science networks. Thus, it constitutes the global IPPOG network of laboratories, institutions, organizations and individuals passionate about physics and fundamental physics research. The expertise of IPPOG's members spans all aspects of collider and non-collider research, including astroparticle and nuclear physics as well as accelerator and detector technology.

Hence, IPPOG is fostering long-term, sustainable support for fundamental scientific research around the world. It brings the beauty of exploring the fundamental constituents of matter and the universe to young people; and it conveys to the public that the beauty of nature is indeed becoming understandable from the interactions of its fundamental parts, the elementary particles. Indeed, the mandate of large research laboratories such as CERN, GSI and others is fundamental research providing the means of a collective, well organized, approach towards the primordial need of humankind to comprehend the primordial universe and its origins, to explore the mysteries of nature. This has been possible by gradually pushing the boundaries of technology and the advancement of necessary tools, such as accelerators, detectors, computing, beyond their state-of-the art at any given moment. Which has naturally led to spin-offs, adapting such technologies for various applications for the benefit of society. The list is long, with very many technologies used for medical applications.

Therefore, IPPOG has put particular emphasis recently on enhancing awareness of benefits for society from fundamental research. The Particle Therapy MasterClass, PTMC, developed in 2019 and integrated in the "International Masterclasses" IMC programme in 2020, introduces high-school students to applications of accelerators in the fight against cancer. The WG Outreach of Applications for Society collects and makes available short stories, covering a wide spectrum of applications. Thus, IPPOG conveys to the public the beauty of exploring nature and, at the same time, provides tangible examples of benefits for society as a spin-off of developments for the needs of fundamental research. Indeed, even technologies developed for future research projects find already applications in hospitals. IPPOG, through its targeted activities, aims at publicising broadly such achievements and making them a common knowledge.

2.Particle Therapy MasterClass

International MasterClasses IMC The IMC programme began in 2005 as an initiative of what was then the European Particle Physics Outreach Group (EPPOG). Since then, EPPOG has become the International Particle Physics Outreach Group (IPPOG), and the masterclasses have grown steadily beyond the group of IPPOG member countries. They give the opportunity, every

year, to over 15,000 high school students from more than 60 countries around the world to become scientists for a day and to immerse in the fascinating world of its fundamental constituents. Invited to local universities and research centres, including some 300 institutes in 2024 and even more in 2025, these masterclasses enable the young students to perform measurements on real experimental data themselves. Thus, they introduce them to the methods of scientific research based on facts and analytical thinking which are the basic to study the mysteries of matter and forces. At the end of the local sessions, the participating institutes join in a common video conference to discuss their results among them, moderated by experts, as various teams of the international research collaboration routinely do. Thus, the IMC programme offers the opportunity to 15- to 19-year-old students to get acquainted with "what scientists do" and get a hands-on experience, highlighting the benefits and need of International Collaborations. The details of the programme and its impact are presented in numerous IMC publications. Indeed, they make science come alive in a way that textbooks never could, bringing students to the forefront of scientific exploration.

IMC Evolution The concept of physics masterclasses originated from the ones that started in the UK in 1997 while the first European-wide Masterclass event took place in 2005 during the World Year of Physics, organized by EPPOG. U.S. institutes followed, joining the IMC programme in 2006. Initially the IMC hands-on packages used experimental data from the CERN LEP experiments. With the startup of LHC, all LHC experiments developed dedicated masterclasses using the LHC data for their hands-on packages. Recently, the IMC programme has expanded and includes the BELLE II, MINERvA and Pierre Auger Observatory dedicated masterclasses. In 2019, the Particle Therapy MasterClass was developed, as a concrete example of medical applications rooted on technologies developed at research laboratories, and since 2020 it has been integrated in the IMC programme. The first PTMC took place, 2nd of March 2020 in Mexico, in person, exactly when covid-19 was spreading which push it to an online mode reaching in 2021 1500 students invited by 37 institutes in 20 countries. Since then, a set of world maps shows the participating countries with a 5th one added in 2025 celebrating the 5-year PTMC anniversary on the 31 March 2025.

PTMC Modes The PTMC aligns with the IMC period, typically between mid-February and before Easter. Several dates are offered to the institutes at the beginning of each IMC season. Then, additional dates are offered adapting to their availability and needs. As an example, in 2025, the PTMC was performed during 12 dates starting 11 February and closing on the 4rth of April.

During each one of these selected days, 3-5 institutes participate as host organisers, with no strict limitation neither on the lower nor on the upper limit. Ideally, institutes invite schools of their areas to their own premises, with the aim to make known to the high-school students their laboratories and installations. Alternatively, scientists of the host institute, organizing the PTMC events, may decide to go to the schools to overcome any administrative difficulties involved with such school visits, or difficulties related to the availability of rooms to perform the hands-on and the lectures at their institutes. As the PTMC was immediately affected, at its startup, by the covid pandemic, it was adapted for online participation, which expanded enormously its reach. Still, several institutes resort to fully online or hybrid modes with the aim to provide such an

opportunity to students in remote places. Indeed, feedback of teachers and students from remote places clearly shows their appreciation and the impact of such events. Some institutes chose one day for in-person session and a different one for an online reaching students in the whole country.

Online PTMC in Greece As an example, the online PTMC sessions organised in Greece are singled out. They were planned and set up, personally, by the PTMC overall coordinator, playing also the role of the "local" PTMC coordinator with the idea to bring together expert Greek scientists from abroad with experts in Greece covering the multidisciplinary fields of particle therapy. The online PTMC takes place on a Saturday to give the opportunity to students to participate while not at school, and to also provide flexibility to lecturers. The agenda is set up with contributions from Greek lecturers working at CERN and GSI focusing on accelerator technologies and their impacts highlighting their role for high precision particle therapy; giving as notable example their use at the GSI heavy-ion research institute that pioneered, in campus, carbon-ion therapy. Other lecturers of Greek origine, working abroad in renown institutes in various fields of radiotherapy, deliver lectures focusing on different aspects of the disease and its treatments, highlighting breakthroughs and the role of their work. Those are complemented with input and experiences of contributors from national institutes, such as the Aristotle University of Thessaloniki, Demokritos in Athens, the Papageorgiou General Hospital the ACHEPA University Hospital in Thessaloniki and others. The welcome address of public figures, such as of the deputy of the governor of central Macedonia makes visible the support of the state; it is also a satisfaction for the local team of enthusiastic AUTH students, who actively contribute in the preparations. They are mostly motivated during lectures in the medical physics courses but not limited. The PTMC in Greece benefits from the indispensable contributions of the Veria Public Library for the PTMC dissemination through its extended networks and also from its TechLab for webcasting through their channel. This reflects in the broad participation that covers practically all parts of Greece including islands, close-to-borders or mountainous regions and other remote places. Already the first year 150 students registered while for the PTMC2025 season the registrations exceeded 250 with sizeable participation to the afternoon hands-on session also and good submission of results, as requested in order to obtain the associated certificate of attendance.

PTMC Typical Day A typical PTMC day is based on the principles and standard programme developed for a typical IMC day. It builds upon and enhances important pedagogical elements that make such masterclasses a valuable educational tool.

In a nut-shell, the PTMCs are performed during the dates selected by the interested institutes following similar agenda, as recommended during the tutorials and available as a general template. Typically, the PTMC day starts with a video to give to the students an overall idea of the basic topic of the day, to ignite curiosity and motivate them. Such animations, mostly prepared by the ENLIGHT network, but also from the European hadron therapy centres, give to the students a visual impression of a particle therapy centre and treatment procedures. This makes it easier for them to follow the morning lectures and put the new information into a general context.

The lectures cover various aspects of the multidisciplinary field of particle therapy. The aim is to highlight how particle physics is related to particle therapy, heavy-ion physics to heavy-ion

therapy, nuclear physics to nuclear medicine. They demonstrate how technology developed due to the needs of fundamental research are adapted for use in medicine and, in particular, for cancer diagnosis and therapy. General lectures explain that the basic principles of participle interactions with matter are the basis of both, particle detection in physics experiments and the underlying mechanism of treating cancer tumours. The lectures can be easily adapted to the expertise of the host institutes, for example, focusing on accelerators technologies, specific detector or software developments, related, in particular, to imaging or dosimetry, the usage of artificial intelligence, but also radiobiology aspects and other related topics.

The morning session finishes with a visit to the institutes laboratories or alternatively with a real-time virtual visit to the ALICE heavy-ion experiment at LHC, dedicated to fundamental research studying strong interactions in heavy-ion collisions. The aim is to showcase the actual laboratories where detectors are developed, and experiments are set up. Several institutes subscribe for the ALICE online visit that the students always find exiting, particularly when there is a chance to visit the experiment underground. This connects the ALICE heavy-ion experiment, dedicated to fundamental research, with the visit of a heavy-ion cancer therapy facility during the afternoon video-conference, thus highlighting the applications for the benefit of society; the message being in short "from physics to clinics".

The highlight of the day is the opportunity that the students have to handle real data during the hands-on session in the afternoon. This interactive activity, but also the realisation that this is something special, creates a strong and lasting impression; and, thereby, facilitates learning and remembering even new information which is provided in a short time.

For the PTMC hands-on session, the matRad open source professional Treatment Planning (TP) toolkit is used, developed by DKFZ, the German cancer research centre, specifically for research and training. In fact, matRad has been benchmarked with professional TP packages used in hospitals and impressive agreement has been reported. However, it is always stressed that matRad is not to be used in hospitals because of the additional quality assurance components required for clinical applications that would make the package more complicated to use for education and research. For the PTMC, a simplified version is used, and an executable is made available via the PTMC web pages; thus, avoiding the need to install MATLAB. The students work on optimising Treatment Plans, for different cases (head-and-neck, liver, prostate etc) that were prepared and made available by DKFZ. These Treatment Plans are prescriptions of the therapeutic dose that the accelerator has to deliver, using photons, protons or carbon ions. In the recent version of matRad the option to also use helium was implemented. This gives the opportunity to the tutors to mention the different properties of particles and their propagation in matter, for example, of protons and helium, which makes helium a better option as it has less lateral scattering. These differences can be important, in particular, when treating children. Such observations and discussions with the students, highlight once more "what physics has to do with medicine".

Then, students can choose the best angles to precisely target the tumour in such a way that the therapeutic dose is deposited in the tumour avoiding organs at risk. They can easily then

compare the different plans and see for themselves the differences between photons and hadrons.

Towards the end of the hands-on session, the students prepare a presentation with their results for discussion, during the local session, if time allows. Then, they present these results in a common video-conference, which is moderated by GSI, and discuss them with all other institutes that performed the PTMC during the same day, but also with particle therapy experts that join from their institutes. When possible, they are offered a virtual visit also; for example, to the historic GSI treatment room, where 440 patients were treated in the 90s, or the accelerators of the CNAO hadron therapy centre, usually shown via a webcam. Alternatively, related videos are available via the PTMC web pages. Thus, students realize that scientists routinely exchange information remotely and not only during the covid times. This already makes clear to the students the importance of collaborating for common projects. The presence and discussion with these experts also highlights the multi-disciplinary aspects of particle therapy. In some of the video-conferences Prof Ugo Amaldi, one of the fathers of Hadron Therapy in Europe, shared his experiences also highlighting the fact that studying physics opens up many opportunities, including medical applications. In others, young researchers join explaining their path and their research details as well as the life and routine of a researcher. Indeed, students really appreciate the common video-conference at the end of a long day and they take the challenge to present their results; usually surprising the moderators and demonstrating how fast young students can learn when they are motivated and given the stimulus to really engage. They also enjoy the presence, comments and eventual discussions with the experts joining from their institutes, that they find interesting but also special and exiting.

During the video-conference, they also have the opportunity to learn about capacity budling initiatives, such as the HITRIplus EU-funded project, that provides educational materials via its YouTube channel and clearly demonstrates the multi-disciplinary aspects of the field as well as the need of close collaborations of different disciplines for coherent advances.

The video-conference finishes with a quiz which is a fun way to finish the day. Some of the questions make them think and realise the physics principles that are the underlying basis for particle therapy, or how accelerators are used in the process. The quiz is run on Kahoot which makes the experience very pleasant.

PTMC Information A lot of material is provided via the PTMC webpages, including the PTMC in a KIT, that contains the necessary and sufficient material to run it. Recordings, written instructions and presentations are available in English and other languages. Specifically, the repository contains instructions for the matRad software installation, a written document with step-by-step explanations and screenshots for windows and mac, as well as recordings demonstrating the installation interactively. It also contains a set of presentations covering an introduction to the basics needed to perform the hands-on and, also, step-by-step explanations for each one of the cases (head-and-neck, liver, prostate) following the suggested workflow provided by the matRad developers. This material was used by several local organisers and translated to their own local languages, which is also available via the same link in separated folders for different languages. This is complemented by the recordings of the various online training

sessions to facilitate newcomers and refresh the skills of organisers and tutors.

PTMC 5-year Anniversary After the first pilots in 2019, in February "local" at GSI and in April "international", at CERN, DKFZ and GSI, the PTMC was approved and integrated in the International MasterClasses IMC programme with its first session on 2nd March 2020, in Mexico, exactly when covid started spreading. This forced the cancelation of the 2020 PTMC sessions but it also fuelled the development of the fully online sessions that took place in 2021 reaching immediately a unprecedentedly large number of students; 1500 students were invited by 37 institutes in 20 countries. Hence, the first PTMC map showing this broad international participation was created. Since then, interest and participation steadily increase with the PTMC2025 marking the 5-year PTMC Anniversary and adding the fifth PTMC map to the growing set. A total of 70 institutes from 37 countries have participated at least once since the first pilots. To celebrate the 5-year PTMC Anniversary a map including all countries that participated since the beginning was created and shown in the figure 1.

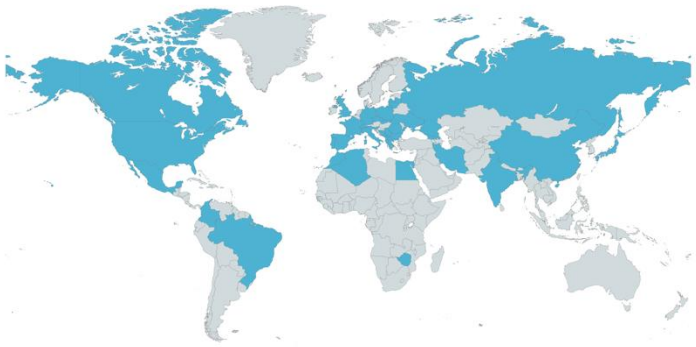

Figure 1: World map indicating in colour the countries whose at least one institute participated at least once in the PTMC sessions as host organiser, celebrating the 5-year PTMC Anniversary since its first global, international PTMC2021 sessions developed fullly online during the covid-19 pandemic. Starting with the first pilots in 2019 by CERN, DKFZ, GSI, and the first in-person PTMC within the IMC program in Mexico, on the 2nd of March 2020, when the coronavirus hit, the participation was extended reaching 70 institutes from 37 countries.

While some institutes participate every year, others rotate performing particle physics or particle therapy masterclasses every other year. Or in some cases they perform the particle physics and particle therapy masterclasses as a joint two-days event; thus, making stronger the message "from physics to clinics" and more obvious the connection of physics fundamental research to applications for cancer therapy. To thank each and every one who contributed in anyway, the PTMC core team wished to give a flavour of "celebration" during the PTMC2025 season. An online 5-year PTMC Anniversary celebration is planned on the 31st March 2025, where all institute organisers and their tutors assistants can join to celebrate together, even if virtually, as the PTMC started. However, all contributors of each institute are encouraged to join and meet in person at their institute, or online from the place where their career path brought them.

As an anniversary celebration party, it is kept flexible and informal. Participants are encouraged to share any material they wish in order to best convey their experiences, including presentations, pictures or videos, some statistics or witnesses that could provide evidence on the

PTMC impacts. While the whole day is reserved to facilitate participation of institutes from different time-zone, people who may not be able to participate were encouraged to upload via a dedicated field of the indico agenda any material they wish to contribute and share with everybody. They are also encouraged to collect any presentations and published articles either in conferences and scientific journals or press. A first attempt had started via the PTMC participation to conference and PTMC articles. The wish is to initiate an effort to collect witnesses, for example about students who followed related studies, enhancing awareness of general public through the families and friends of the students or their social networks, enhancing awareness at political levels and other impacts. The ambition is to make available such materials via web pages in an organised visible way. Finally, the artists among the PTMC contributors were called to submit proposals for a Logo.

PTMC Training About five online training sessions are organized every year on zoom to support the host institutes. Recordings, written instructions and presentations are available in English and other languages. In addition, one-to-one training sessions are organised upon request, which is often the case for newcomers. Training teachers is also very important, and training sessions were organized during the IPPOG spring meetings in Sofia and Madrid. Exemplary is the approach of the UNSA Sarajevo university that created a pool of trained teachers who perform PTMCs in their schools, following remotely the introductory morning lectures. This ensures that a bigger number of high-school students can benefit from the PTMC than those that can be hosted in the premises of the university. It also facilitates participation of schools from remote places of the country. The introductory lectures are also given by UNSA students engaged in related studies in international institutes, thus providing an inspirational example to the high-school participants.

PTMC Training at IPPOG meetings The spring IPPOG meetings give the opportunity to offer to the host institute some additional activities. During the spring IPPOG meetings in Sofia and in Madrid the PTMC was chosen, and special sessions were set up at the end of the IPPOG meeting. Hence, associated to the IPPOG spring meeting 22-25 April 2024 at CIEMAT, a hands-on practical demonstration of the contents of the IPPOG Particle Therapy Masterclass took place in the morning of Thursday 25 April, as part of the CIEMAT Particle Physics seminars. The aim was to introduce researchers interested in conducting the PTMC in their home institutions in the future, as well as high school teachers already acquainted with the International Masterclasses programme. The tutorial started with an introduction on the PTMC concept and practical details for potential future organisers and moderators by the PTMC coordinator. She stressed that one of the aims of this masterclass is to emphasise the practical applications stemming out of technology advances for fundamental research and, also, different career opportunities that STEM studies may offer in related fields. She also emphasized that the PTMC format was very successfully implemented for full week hadron therapy schools by the EU funded HITRIplus project and the role of the IPPOG network for their dissemination. This was followed by an online presentation on cancer therapy, highlighting hadron radiation therapy advantages, the Head of the Division of Biomedical Physics in Radiation Oncology, of the German Cancer Research Centre, DKFZ, in Heidelberg. The highlight of the tutorial was the hands-on demonstration by DKFZ expert using the matRad open source Treatment Planning toolkit. He first introduced TP concepts pointing out

its importance for enabling best control of a cancer tumour while sparing the healthy tissue and critical organs. He then performed, interactively, treatment plans, using the provided data, while participants followed his instructions. After showing the basics, with a so-called "phantom" which is used to simulate as closely as possible the human body consistency, he performed TP for several cases guiding participants and providing in depth details. This stimulated several questions and lively discussions mostly among the about 20 participants following the tutorial in person while online participants had also their share. The event was followed by a total of about 50 registrants. For future reference, the tutorial was recorded and made available in YouTube. As time was rather short, participants were pointed to the PTMC home page where further material is provided including animations, as well as detailed instructions and recordings. They all expressed their interest and satisfaction with enthusiasm as well as their appreciation to the speakers and IPPOG organisers. Indeed, such initiations to Particle Therapy are most welcome as Spain acquired ten proton therapy centres donated by a well-known cloth enterprise. The developed pattern and agenda are used also by other institutes wishing to provide training in a rather short time.

PTMC in Algeria Masterclasses in general play an important role in Algeria. The teacher behind the efforts to spread it in the whole country often shares progress with the IMC organisers. He reported that recently, significant progress was achieved with the Algerian Masterclass project. It received considerable support from the Ministry of National Education and the Ministry of Higher Education, both committed to integrating scientific research into the national education system. This step is expected to enhance the learning experience and bring research-centered approaches into the classrooms.

A successful two-day training session was conducted in Algiers with 52 teachers from 26 high schools representing various regions of Algeria. This gathering was an excellent opportunity to connect with educators deeply committed to advancing science education. Special attention was put in the logistics coordinating their registration to the IMC2025 programme, individually, to facilitate selection of suitable dates and to ensure a smooth experience for all. A logistical adjustment is being implemented regarding the scheduling of the videoconference in order to allow students to participate fully and still return home comfortably within the same day.

Additionally, after the 2025 Masterclasses, the plan is to organize a competition, in April, to recognize outstanding students, culminating in a formal ceremony to honour their achievements. The expectation is that the Minister of Education is going to join for this occasion.

PTMC Inclusion, Diversity Targeted efforts are made to encourage female participation, providing role models and celebrating women's days on 11 February and 8 March. Every year the PTMC reaches more than 1500 high-school students hosted, in 2024, by 48 institutes in 22 countries, spanning from Japan to Latino-America and Africa.

PTMC Impact Many assistant tutors have been motivated to follow related studies and become active members of the community being also supported by the Heavy Ion Therapy Research Infrastructure HITRIplus project, its opportunities and its partners.

As a concrete example of the impact of the PTMC, its evolution in North Macedonia is often

used. It is an example of the student becoming then tutor and organiser; providing a role model to the high-school students but also influencing the society and policy makers. Indeed, the need to resort to online means during the covid-19 pandemic made it possible for the PTMC core team organisers to reach their colleagues and professors in their home countries remotely. One of them, working within the GSI Biophysics department and originating from the south-east European region, organised an online PTMC session, first, for the professors and their university students of her hometown. Institutes from different countries speaking the same language participated and got trained. One particular student among them was motivated to follow related studies for her Masters. She chose as a subject of her thesis work the comparison of treatment plans based on photons for real breast cancer cases with treatment plans obtained with matRad using protons and carbon-ions. While she is applying for continuing with a PhD, she is teaching at a medical high-school and working as an assistant at the university. Together with her university physics professor they organise PTMC sessions every year since the beginning of the programme. Working herself in a high-school and being connected with high-school principals and teachers, makes it easier to disseminate the PTMC. The PTMC organised in-person at the university typically attracts up to 300 high-school and had to be limited to 200 participants. Also very sizeable is the participation to the online PTMC session which expands the reach to many regions of the country. For the hands-on sessions they high-school students bring their own laptops. This implies that the matRad software has to be installed in advance in the students' laptops, as it is the case for the online sessions. Therefore, she has prepared well-structured instructions and materials in the local languages. Also, before the PTMC session, students are organised in different teams, depending on the schools they come from, and work on the preparation using online applications. All groups are invited to present locally their results before the common video-conference; and they are very eager and proud to do so. During the PTMC2025 session the PTMC overall coordinator was invited for an in-person presentation in the PTMC session celebrating the International Day of Women and Girls in Science. This gave the opportunity for additional activities beyond the meeting with the university rector. Those included a presentation to an international school attended by 150 girls and fruitful discussions with their teachers and the principal of the school; but also a visit to the minister of science and education extending the discussions to the very relevant subject of the curricula at every stage of education. Further visits included the oncological hospital and ministry of health highlighting the progress in radiation therapy and benefits of particle therapy. They all agreed to bring the matter to their prime minister and further pursue progress wishing to make available hadron therapy in the region.

Heavy Ion Therapy MasterClass Following the pattern of the PTMC, its well-established methods and tools, as well as its pedagogical elements, the Heavy Ion Therapy MasterClass, HITM, was organized within the framework of HITRIplus for early stage researchers and up to professionals. The event adjusted at appropriate levels, through lectures delivered by experts in the field of heavy-ion therapy, attracted 1050 participants world-wide, many of them becoming, subsequently, PTMC tutors. Further details on PTMC/HITM are given in references [1-5] and on matRad in [6]

3.Outreach of Applications for Society

Concrete examples of successful applications for the benefit of society from (particle) physics and related sciences are among the most effective means to communicate the positive impact of fundamental research to society when approaching the non-scientifically educated public. In addition to the quest for knowledge and satisfying natural human curiosity, there is a growing pressure, from taxpayers, for the justification of fundamental research funding, requesting tangible examples of return to economy and society. A particularly important target group is the young generation, who needs to be motivated and inspired to engage in STEM studies. Furthermore, the ones who engage with STEM studies need to be exposed to perspectives on potential careers and to examples of the impact of fundamental research to applied sciences.

Thus, the aim of the Working Group "Outreach of Applications for Society" is to offer a structured and categorized online collection of short stories with clear messages and explanations of "science at work" in the applications and spin-offs. The ultimate goal is to connect fundamental science to everyday lives of citizens and solutions for global societal challenges.

Out of a wide range of working documents and even more ideas, the stories available at the time of writing are listed below and they are available via the: IPPOG witness stories web page

- Unraveling Cosmic Mysteries: The collaboration between International Space Station and CERN
- Superconductivity – quantum mechanics at work
- Medipix detectors, from colour X-ray imaging to education
- Muography - Invisible particles help to reveal invisible structures
- Searching for hidden cavities inside the Sun pyramid in Mexico
- Einstein's Relativity in Action – the GPS Navigation System knows it
- Positron Emission Tomography: Can crystals used in particle detectors save lives?
- Accelerators to reduce pollution of maritime traffic

Indeed, in today's pragmatic, technocratic society, accustomed to flow of information, concrete examples on the impact of science, readily available, are needed to reach different target groups. The WG set itself the challenge of providing engaging stories with a human touch, trying to inject a personal note and trigger the so-called emotional memory; thus, approaching audiences and inspiring the young generation through "story-telling".

After collecting materials, from sources such as Books, Accelerating News, CERN knowledge transfer, GSI news and press releases, but also individual contributions, the WG works on story-building around the available facts while trying to find anecdotes and add a human touch to each one of them. Certainly, the idea is not to re-write what exists, but to present the existing material in a way that further triggers curiosity and motivates individual research; that approaches the reader injecting something personal, when possible.

The WG provides guidelines for anyone wishing to contribute, and a lot of accumulated resources as a starting point. The initial idea was to keep the stories short and simple; however, they also need to be accurate giving credits and highlighting the importance of collaborative efforts. Indeed, the final outcome is usually the result of ideas and work of many different groups which culminates often in large research laboratories. Each "story" focusing on a certain application has to explain what it is good for, how it works (limiting to the necessary technical

details that physicists are always eager to provide), and if possible, to mention a personal connection, a human aspect. The initial idea was to address "general public" which, however, contains a very broad spectrum of target audiences. Hence, the WG had to take a pragmatic approach, addressing primarily students and teachers; and, therefore, the "stories" provide links to further materials, for those wishing to go into more details.

In practice, the work had to be adapted "on the go" and the WG tried different formats. For example, the explanation of the general principle of "muon tomography" is presented in one story. Then, as an application of this general principle, the explorations of the ALICE/UNAM group, searching for hidden chambers in the "sun pyramid" in Teotihuacan, Mexico, is presented in a different story. And those are, then, cross-referenced. Another example is the PET story, where the first page presents general information; and then, further details are given, like "addenda".

In addition to the above list of stories, which is the outcome of two dedicated hackathons, the current list of topics in the pipe-line includes subjects spanning from the well-known development of www, to cancer therapy, UNOSAT, touch screen, and many more. Almost unnoticed, about 30 000 accelerators are operating worldwide for the benefit of society based on the breakthrough developments of a handful of them dedicated to fundamental research. They are used for medical, industrial, security, environmental applications including possibilities to more effectively treat wastewater or sewage sludge. The ambition of the WG is to make such facts easily accessible to non-experts while presenting human aspects of scientists at the same time.

The stories are available for everybody to use to stimulate interest for STEM studies: for example, a colleague in Mexico presents them to school children motivating them to become ambassadors; another one extends the WG impact participating to a broader project, Youth@STEM4SF piloted in Switzerland supported by BeLearn, that explores the possibilities to enrich high-school curricula by including modern physics and creating digital materials. The aim is to develop new teaching tools, including the topic of hadron therapy, to enable physics high-school teachers to connect basic sciences with societal challenges and sustainable development.

Acknowledgements

I would like to acknowledge the support of all IPPOG colleagues and, in particular, of the IPPOG core team, the WG "Outreach of Applications for Society" members and co-convener Barbora Bruant Gulejova, the IMC Steering Group and all the PTMC teams and contributors.

WG Outreach of Applications for Society: I would like to acknowledge the contributions of all colleagues that supported the WG efforts in any way, including written stories and material, or brainstorming discussions and advice.

PTMC: I am indebted to many of my colleagues at GSI and CERN; it is not a coincidence that the PTMC was developed with the support of both. Special thanks go to C. Graeff GSI and N. Wahl DKFZ for introducing me to "treatment planning"; to the DKFZ and LMU colleagues for providing the matRAD toolkit and eagerly supporting the PTMCs and HITHIplus schools; to the ENLIGHT coordinator for guiding me in a new territory, and providing material; to the UNSA and AUTh students that contributed setting up the PTMC web pages, dedicated trainings, material in local languages etc; to the UNAM students, for setting up the "PTMC in a kit" first in Spanish

and then in English; to ALICE, GSI, CNAO, DKFZ colleagues for being eager to offer real-time online visits and help moderate video-conferences; to the core team of volunteers for keeping up with the work and challenges that came with the growing interest, in particular the PTMC2024 and PTMC2025 core team that successfully managed the participation of about 50 institutes world-wide, headed by N. Muradi, Uni Tetovo who motivated by the PTMC followed related studies. Last but not least the NIMMS group, the ARIES, I.FAST, HITRIplus (G.A. No 10100 8548) EU-funded projects, and the "Three Physicists Foundation" that embraced the PTMC. It is indeed a great satisfaction to witness the PTMC impact and experience the feedback of students at all levels. I would like to acknowledge the support of all colleagues that contributed to this endeavour.

References

[1] L. Graczykowski, P. Nowakowski, P. Foka, *New developments for ALICE MasterClasses and the new Particle Therapy MasterClass*, in proceedings of *CHEP 2019 conference* EPJ Web Conf. 245, 08011 (2020) CHEP 2019, e-Print: 2005.02215 [physics.ed-ph]

[2] P. Foka, *Particle therapy masterclass,* in proceedings of science, Volume 398, EPS-HEP2021

[3] P. Foka, A. Mamaras, D. Skrjiel, J. Seco, C. Graeff et al. *Particle therapy masterclass,* in proceedings of vCONF21, EPJ Web Conf. 258, 01002 (2022)

[4] A. Mamaras, P. Foka *Concepts and Methodology of the Particle Therapy Masterclass (PTMC) For Capacity Building – PTMC in Greece as a Case Study* in International Conference on Accelerators for Research and Sustainable Development, IAEA 2022 https://inis.iaea.org/search/search.aspx?orig_q=RN:53084702

[5] P. Foka, A. Mamaras, *Heavy Ion Therapy MasterClass School and Capacity Building For Future Ion Research and Therapy Facilities* in International Conference on Accelerators for Research and Sustainable Development, IAEA 2022 https://inis.iaea.org/search/search.aspx?orig_q=RN:53084618

[6] Cisternas E., Mairani A., Ziegenhein P., Jäkel O., Bangert M. (2015) *matRad - a multi-modality open source 3D treatment planning toolkit.* In: Jaffray D. (eds) World Congress on Medical Physics and Biomedical Engineering, June 7-12, 2015, Toronto, Canada. IFMBE Proceedings, vol 51. Springer, Cham.

[7] B. Bruant Gulejova, "*Shaping high school science education with tech industry in action for sustainable development*", Youth@STEM4SF, Swiss Phys. Soc., SPG Mitteilungen Nr. 73, June 2024.