HEAVY ION THERAPY MASTERCLASS SCHOOL AND CAPACITY BUILDING FOR FUTURE ION RESEARCH AND THERAPY FACILITIES.

Panagiota FOKA
GSI Helmholtz Centre for Heavy Ion Research Darmstadt, Germany
Email: yiota.foka@cern.ch, p.foka@gsi.de

Aristeidis MAMARAS
Aristotle University of Thessaloniki Thessaloniki, Greece
Email: amamaras@physics.auth.gr

Abstract

The Heavy Ion Therapy MasterClass school took place, online, in May 2021, for first time, attracting over a thousand participants. The unexpected and unprecedented high number of participants, spanning from undergraduate students to practitioners, shows the increasing interest in heavy-ion cancer therapy research and related training. It also demonstrates the enormous potential of the next generation, represented by the young students and early-stage researchers that can then optimally access the heavy-ion therapy centers and become the experts of next generation facilities. The main emphasis of the school was on the use of accelerators for the treatment of cancer tumours, highlighting the role of research centres with prime example the GSI heavy-ion research centre where carbon-ion therapy was pioneered in Europe in the 90s and from where it was implemented in the first European dedicated ion therapy centre. The main feature of the school was its multidisciplinary and interactive approach which stimulated participants, despite its online format. Overview lectures provided the necessary panorama, while focus lectures presented details including medical accelerators and accelerator physics highlighting the importance of the development of novel accelerator technologies. The scientific programme was shaped to target topics in emerging fields, highlighting the role of fundamental research in developing new applications in medicine, particularly cancer diagnostics and treatment. The participants' feedback clearly demonstrated their appreciation, including the inventive format of the school which is described in the paper as means to support capacity building in related fields and in particular in accelerator specializations.

1. INTRODUCTION

The Heavy Ion Therapy Masterclass, HITM, school [1] was organised 17-22 May 2021, "in Sarajevo", but in reality, fully online due to the covid pandemic. It was organised free of charge, within the framework of the HITRIplus [2] project funded by the European Union's H2020 research and innovation programme. It provided a full-week international online masterclass course on heavy-ion cancer therapy research inspired by the format of the Particle Therapy MasterClass, PTMC [3]. Motivated by the received feedback on the PTMC, its format and pedagogical elements were employed for the HITM school. Hence, the school combined lectures with hands-on sessions on treatment planning that were delivered by world's top experts in the field. Leading institutions, research centres, ion therapy facilities, and industry collaboration contributed to its success and conveyed the message that technologies developed for fundamental research find applications for medicine. It was attended by 1050 participants, from all over the world, that ranged from undergraduate students to Masters, PhDs, early stage researchers but also professional lecturers and practitioners; and involved a total of 36 speakers. Participants greatly appreciated the multidisciplinary approach of the school and the presentations from leading experts that started from basics and covered most recent developments and future perspectives in heavy-ion therapy research.

The school run smoothly, it provided enough interactivity, and had a big impact despite the big challenges. Surveys and comments of participants summarise its main elements that distinguished it: its approach, regarding the content, but also its format, was "holistic, multidisciplinary, and original". A "spiral approach" was followed including, from the first day, all topics relevant to heavy-ion therapy, starting with overview presentations and gradually progressing to deeper details, not taking shortcuts. So, beginners and participants from different fields could comfortably follow, advancing every day in all topics, in parallel. Speakers, leading experts in their fields, starting from basic principles, elaborated on topics spanning from accelerator technologies to clinical related subjects. It thus gave the opportunity to have an overview of heavy-ion therapy but also included the last day, state-of-the-art science and cutting-edge technology developments as well as future trends.

Several articles summarised the school including ENLIGHT [4] and CERN Courier [5] while its presentations and recordings are available openly, for anyone interested to follow them, via the HITM school [1] and HITRIplus [2] web pages.

1. HITRIPLUS PROJECT AND SCHOOLS

The HITRIplus [2] is a large consortium of research infrastructures, including CERN [6] and GSI [7], universities, industry, the four existing European heavy-ion therapy centres, and SEEIIST, the South East European Institute for Sustainable Technologies [8]. Its main aims are to support: (a) transnational access, (b) new developments for the future SEEIIST facility and upgrades of the existing ones (c) networking, training and education (capacity building) in related fields in order to sustain the existing and future heavy-ion facilities. Thus, it brings together, the four heavy-ion therapy centres in operation in Europe, including the biophysics programme at the GSI heavy-ion research centre, and opens them in a coordinated way to the medical and research communities. Intensive design work focuses on the design of some novel components of next generation medical accelerators and facilities for cancer tumour therapy research with heavy ions, in collaboration between all partners, based on the expertise of advanced research institutes and of the main European ion therapy centres.

Within the HITRIplus education and training work package, three schools were foreseen, addressing mostly promising early-stage researchers that could then optimally access the European heavy-ion therapy centres. The first one, the Heavy Ion Therapy Masterclass school, started with setting up the basis assuming no prior expertise and putting a strong emphasis to also support capacity building in South East Europe that is lucking expertise in related fields. Hence, the next two schools will explicitly target young researchers that are more advanced in heavy-ion therapy specialised studies. The second HITRIplus school is also planned online, in July 2022, while the third one is envisaged currently in-person or hybrid mode. In order to facilitate sustainability and help create a “cascade effect”, spreading to the max the acquired knowledge, they all foresee “train-the-trainer” sessions. The aim is to train tutors that could then perform back at their home institutes the Particle Therapy MasterClasses [3], that are one-day events addressing high-school students and are described further in the paper and in related conference proceedings [9, 10, 11]. The initial plan was to organise the HITM school in Sarajevo as a further support for ongoing capacity building activities involving the UNSA university [12] which also contributed to the PTMC project. However, due to the covid pandemic it was organized fully online which made possible world-wide participation. The HITM school was the first event of HITRIplus. The interest that attracted, the enthusiastic response of participants and their praising comments, underlying its success, strongly motivated all HITRIplus collaborators to focus on the work ahead.

2. HEAVY ION THERAPY MASTERCLASS SCHOOL

The scientific programme of the Heavy Ion Therapy Masterclass school was shaped to target topics in emerging fields, highlighting the importance of fundamental research and the role of research centres for developing new applications in medicine, particularly the use of accelerators for cancer diagnostics and treatment. Speakers from the heavy-ion therapy centres in Europe contributed highlighting the relevance of fundamental research and its applications for cancer treatment. Participants realised that challenges set by the research projects’ ambitions push high-tech technology which ultimately translates to benefits for society.

The focus of the school was on heavy-ion therapy and its facilities, as presented in the virtual therapy centre of Fig. 1 (curtesy of ENLIGHT) and which was used as a “roadmap” to shape the agenda of the school, starting from the ion sources and all the different elements that bring the beam to the target. It also included hands- on sessions, focusing on treatment planning (Fig. 2), which is the prescription of the therapeutic dose that the treatment accelerator has to deliver. Addressing also the results of the treatment, it included presentations on the radio-biological effectiveness and characteristics of different irradiation modalities. Participants greatly appreciated having the full image: what happens from the beginning to the end. Indeed, one of the main features of the school was its multidisciplinary approach which presented the multidisciplinary facets of heavy-ion therapy and inspirations for interesting career paths in many different fields.

The school was intended for students interested in medical physics and engineering or related subjects which shaped the agenda accordingly including accelerator and magnet technology, gantry design, beam dynamics, medical imaging, biophysics, radiobiology, dosimetry, treatment planning, clinical aspects of particle therapy, and entrepreneurship aspects of medical research infrastructures. The aim was to attract students that show strong promise and interest to become part of the heavy-ion research community and can then exploit the European heavy-ion therapy research infrastructures. The breakdown of its 1050 participants has shown that participants ranged from undergraduate students to Masters, PhDs, early-stage researchers but also professional lecturers and practitioners. While the participation of about 275 undergraduate students may open them new horizons, the comments of the about 650 Masters, PhDs and young researchers have shown that the HITM school has provided them support and material for their research but also triggered new ideas and collaborations.

FIG. 1. Virtual ion therapy center (courtesy of ENLIGHT).

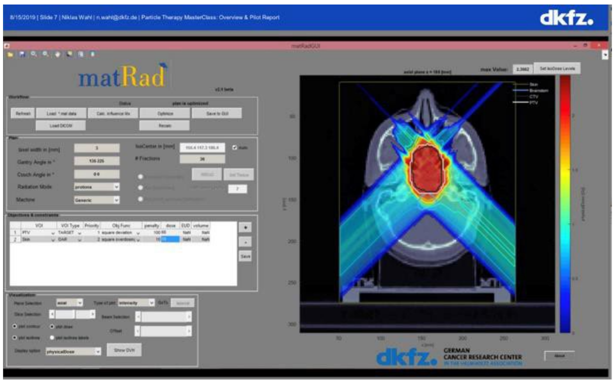

FIG. 2. matRad Treatment Planning toolkit (courtesy of DKFZ).

School format: The format of the HITM school integrated and expanded the basic elements of the masterclasses, as they are performed within the International MasterClasses IMC programme [13], and in particular of the Particle Therapy MasterClass [3]. These masterclasses are one full-day events, that give the opportunity to high-school students to become scientists for a day. The IMC programme runs every year, from mid-February to mid-April, and 2-5 institutes, every day, around the world, invite high-school students to participate, ideally at their premises or online, adapting to the covid pandemic. Thus, the IMC programme attracts every year about 15 000 high-school students from 60 countries involving 255 institutes world-wide. The main aim is to introduce the students to scientific methods by giving them the opportunity to handle real data initially coming from particle-physics experiments at CERN, first from LEP and then LHC. Further expanding its reach, the IMC programme includes currently additional experiments and, most importantly, the new Particle Therapy MasterClass PTMC [3]. The PTMC focuses on applications of accelerators for medicine demonstrating benefits for society from fundamental research that is pushing relevant technologies. Indeed, starting from the first pilot PTMC in 2019 involving GSI, CERN and DKFZ [14], the PTMC in 2021 and 2022 attracted about 1500 high-school students from 20 countries and 37 institutes each year. It was then adapted to address also university students and has expanded its reach to a new generation of scientists.

Therefore, motivated by the received feedback, the format of the newly established full-day Particle Therapy MasterClass, PTMC, and its pedagogical elements, were employed and adapted for the full-week Heavy Ion Therapy MasterClass, HITM, school addressing early stage researchers. The PTMC agenda includes introductory lectures and visits to an experiment or a lab, which is followed by a hands-on session offering the experience to handle real data. Students then prepare a presentation with their results for discussion in a common video- conference among all participants, moderated by an expert. Indeed, as participants commented, an important aspect that characterised the HITM school was its format which, similarly, included a multitude of pedagogical elements facilitating learning: lectures in the morning; hands-on in the afternoon; students' presentations and discussions of their results with experts; online virtual visits to existing therapy centres guided by their experts; every day started with heavy-ion therapy related videos while participants were connecting; every day ended with social events to provide opportunities for networking and entertainment; the last day was dedicated to "future developments" in the field of heavy-ion therapy research and a "careers fair" in the evening.

Online lectures: Every day the online lectures sessions started with a video, showing an ion therapy procedure in an ion therapy centre to trigger curiosity and interest. Furthermore, it provided an overall visual impression, so that students could relate the specific presentations that followed to the broader image and procedures. The lectures covered a wide range of inter-related topics, supported by videos as much as possible, to keep the interest of students. The first day overview lectures provided the necessary panorama spanning from cancer statistics, benefits of heavy-ion therapy, medical accelerators up to radio-biology related topics. Introductory lectures covered the basics of cancer biology and treatment options, the physics and biology of exposure to ionizing radiation, imaging devices and detectors, as well as accelerators used for cancer diagnosis and treatment. Then, focus lectures presented details, for example, on accelerator physics including ion sources, beam optics, beam delivery systems, controls, as well as exploring linear accelerators for radio-isotope production. These were complemented by contributions on fundamental detector or software developments that are used in medicine for imaging, diagnostics, dosimetry, as they are critical parts of the treatment procedures where, also, the impact of breakthrough developments for physics experiments becomes clear. Experts from the European ion therapy centres contributed with their expertise from the users' point of view.

Highlighting the use of accelerators for society, students were surprised to learn that from about 30 000 accelerators that are in operation world-wide, about 6% is used for research, while 1/3 is used for medicine and the rest for different industrial applications. Adapting technologies and methods developed for fundamental particle physics research, sophisticated medical accelerators can deliver particle beams at a desired depth targeting a tumour, thus becoming an important tool for cancer therapy. Advanced accelerator technologies developed for future projects (such as the proposed future CERN CLIC project) are currently explored for the most advanced therapies (such as FLASH therapy).

The importance of computing and software developments was also highlighted including specialised lectures on accelerators control and machine learning techniques and their possible applications in these fields. Experts of the Cosylab hi-tech company contributed to these targeted lectures and made the connection to industry, a natural continuation providing job opportunities. Such opportunities were further highlighted during the last day careers fair organised in the framework of the social events where the experts of this world-wide leading company organised an open house stand and answered questions of interested participants in the highly specialised field of accelerators controls.

Hands-on: The hands-on sessions on treatment planning were offered every afternoon by DKFZ experts, except for the last day that was dedicated to future developments. First, dedicated lectures introduced the students to necessary concepts such as the concepts of dose calculation, dose optimization and radiotherapy treatment plans. In particular, students could realise here how elemental mathematical concepts (e.g., learned from calculus) are required and applied to solve actual technical problems. The hands-on session itself was based on the matRad open-source treatment planning toolkit (Fig. 2) developed for research and training by DKFZ, the German Cancer Research Centre [15, 16, 17]. MatRad is used to simulate and optimize the therapeutic intensity-modulated dose distribution that the accelerating structures have to deliver to the tumour. While matRad's computations were validated with commercial treatment planning software actually used for therapies, it is not licensed for treatment itself but uses a GPLv3 open-source license. This facilitates matRad's lightweight, flexible, accessible and performant code, useful for research and educational applications. Furthermore, depending on the level of the students, special educational versions can be provided with reduced treatment planning complexity of the GUI.

During the first hands-on session of the HITM school students were introduced to the possibilities of the matRad treatment planning toolkit and were guided through the installation procedure that the DKFZ expert tutors performed online step-by-step based on the instructions document that was attached to the agenda. The tutors also handled any difficulties and problems that the participants experienced during installation.

The next three hands-on sessions were dedicated to using matRad to prepare treatment plans. So, students guided by the DKFZ experts had to prepare their "prescriptions", using photons, protons or carbon ions. During this stage, but also during the discussion of their treatment plans, students could appreciate the differences of these radiation modalities and use them optimally according to different cases. These cases were based on data, also provided by the DKFZ experts, and included a TG-119 phantom and anonymous computer tomography (CT) scans of head, liver and prostate tumour cases from the CORT dataset [18]. MatRad includes a graphical user interface (GUI) resembling typical commercial systems to present the data in 3D, provides possibilities to rotate interactively and presents slices in 2D projections. The GUI includes graphical tools to visualize the beam directions and volumes to be irradiated. These capabilities were heavily used by the school participants to visualise and optimise their treatment plans. For the dose optimisation, one can use multiple objectives and constraints for dose prescription, e.g., define a minimum and/or maximum dose value to be achieved within a structure or organ [17]. The visual result on the display, based on a colour scale, is very intuitive to comprehend and easy to associate with the resulting histograms of the delivered dose to the target tumour and organs at risk to avoid. Students can select different angles for irradiation to minimize the deposited dose in each trajectory while accumulating the required dose in the target volume. They can witness the different characteristics of protons and carbon ions, that, in contrast to photons, deposit very little energy in the tissues before and practically none after the tumour.

The hands-on sessions were divided into three sections focusing on a certain theme and demonstrating specific properties. The first section was planned with the aim to highlight the difference of photon and charged particle irradiation on the TG-119 phantom, showing, for example, that many beams are required with photons to cover the tumour while the sparing of healthy tissue can be challenging, whereas protons achieve at least similar results with already one or two beams. The second part introduced carbon ions and radio-biological effectiveness on a patient case using the liver and/or head-and-neck case for this exercise. This also introduced versatility to the later videoconference where students presented their results and discussed their findings. The last part critically introduced the "downside" of charged particle therapy, that is, its sensitivity to uncertainties that might change the net range in the patient and distort the planned dose distribution when the patient is, e.g., misaligned.

Hands-on tutors: Participants were really thankful to their tutors, as was witnessed interactively by their enthusiastic comments on the zoom chat but also via the surveys. Indeed, the DKFZ experts managed impressively well the challenging hands-on despite the huge number of participants; one of them was handling questions and problems while the other one was performing the steps of the exercises, based on a write-up that was attached to the agenda. Participants could then repeat and/or complete the exercises based on the recordings that were made available immediately after the end of the session. This was also crucial for the participants at different time zones.

Hands-on results and attendance certificates: Despite the challenges of the school's online mode, the large number of its participants and the different time zones, 180 participants delivered their hands-on results for all days; and 158 were granted a certificate of attendance fulfilling all conditions.

Students' sessions topics: The HITM school gave special attention to students' dedicated sessions. During those sessions, the students were meant to present their hands-on results but also their research activities. Each day the students' session was planned around a certain focus theme. Monday was dedicated to the installation of the matRad treatment planning software. Then, on Tuesday the theme was "from physics to clinics" going from the GSI heavy-ion research centre to the CNAO [19] running heavy-ion therapy centre. Wednesday was dedicated to treatment planning involving experts from CNAO presenting the tools they use for therapy, from the room where they were working on real cases. This was then contrasted to the matRad tools for training and research. On Thursday, the focus was on the International MasterClass programme and the preparation of tutors for the Particle Therapy MasterClasses, practically a "train-the-trainer" session aiming at sustainability. On Friday, the focus was on future facilities, their upgrades, future trends and perspectives; it culminated with the careers fair, during the social events, presenting career opportunities to interested participants and further supporting networking.

Train-the-trainer: One of the afternoons HITM school sessions was dedicated to introducing the IMC programme focusing in particular on the Particle Therapy MasterClasses with the motivation to support sustainability by training the trainer. The aim was to provide the means to the HITM school participants to become tutors, in their turn, performing the PTMC in their home institutes for high-school students; thus, further supporting capacity building in this specific heavy-ion cancer therapy area.

First, the IMC concepts and programmes were presented by the IMC organisers. Then, the results of a Master's student study, from the UNSA university of Sarajevo, demonstrated the pedagogical value of the one-day masterclass events for high-school students. Indeed, specifically designed surveys and analyses of the accumulated data have clearly shown that students can learn a new topic, even during the one-day masterclass sessions, because of the variety of the employed pedagogical interactive methods and in particular the hands-on experience handling real data and methods.

Next, the necessary concepts and tools for the Particle Therapy MasterClass were introduced highlighting the provided support by the PTMC core team. In order to support the PTMC local organising teams of each participating institute, and prepare their tutors and moderators, weekly dedicated tutorials are offered every year during the IMC seasons but also training sessions at request. The PTMC web pages [3] provide a large variety of material in several languages, including links to the "PTMC in a kit" google drive which contains the necessary material needed to perform the PTMC, including recordings with instructions. In addition, it links to the indico agendas of institutes that performed already the PTMC, including their presentations and other useful material in their local languages. Instructions for installing the matRad specific software are also available via the PTMC web pages, including recordings, explaining the simplified version that was prepared by the DKFZ colleagues for the purposes of the PTMC for high-school students.

Online visits and discussion of results: The HITM lectures were complemented with online visits to heavy-ion research and heavy-ion cancer therapy centres during the afternoon common video-conferencing sessions planned with the aim to discuss the hands-on treatment planning results with their experts. The online visits started with the GSI experimental room where carbon ion therapy was pioneered in Europe, in the 90s. Students were impressed to learn that an experimental room was transformed to a therapy room where some 450 head-and-neck cases were treated with carbon ions and actually see it and listen related details. The virtual visit also included explanations about the pioneering methods of raster scanning [20] and in-room imaging that were then implemented in the hospitals. Indeed, carbon ion treatment of cancer tumours was first implemented in the Heidelberg Ion Therapy centre, HIT [22], based on the GSI successful results showing that 95% of their patients did not present side effects after five years. The GSI experts highlighted that while patients are now treated in dedicated therapy centres, the GSI historic therapy room and its specialised equipment is used for research focusing on the optimisation of treatment of moving organs such as lungs. This virtual visit to a heavy-ion research centre was followed by visits to running heavy-ion therapy centres starting with the CNAO ion therapy centre. The online visit started with a guided tour to its accelerator complex via the dedicated webcam system and included details on its structure and devises given by the CNAO expert technical coordinator who enriched the visit discussing his personal experiences during the design and construction of the accelerating and beam delivery structures. These virtual visits focusing on the technical aspects of the medical accelerators, made it clear to the students that this is the heart of the heavy-ion cancer therapy centres. Then, the focus of the virtual visits was shifted to the significance of the treatment planning. The HITM school participants had the opportunity to see the action in the CNAO respective control room where the CNAO experts presented treatment planning of real cases and their tools. Those were then contrasted to the matRad toolkit tailored for research and education purposes. Indeed, experts from these institutes provided an excellent interactive help, commenting on the students results and answering their questions. These online visits further highlighted the connection between heavy-ion physics and heavy-ion therapy and have clearly demonstrated the relevance of fundamental research and its applications for cancer treatment.

In general, the HITM school highlighted that technology and knowledge transfer "from physics to clinics" resulted in the four carbon-ion therapy centres in Europe. Furthermore, following the PIMMS initiative [21], accelerator experts of the CERN NIMMS group work currently on the design of components for a next generation ion therapy machine adapting hi-tech technologies for medical accelerators. Of particular interest are developments on the so-called gantry, which is the beam delivery system that rotates around the patient to deliver the ions from all needed angles. This was addressed in specialised focus lectures, presenting options for future smaller constructions, by factor about 10 lighter than the existing one in the Heidelberg Ion Therapy HIT [22] centre which weighs 600 tonnes. As an example, Fig. 3 shows the accelerator layout and architect's concepts (courtesy "Kaprinis architects") for a heavy-ion therapy facility which is proposed to be built in South East Europe (SEE). Indeed, the HITM school was followed by several students from SEE countries that they can then become tutors in their turn performing the PTMC in their home institutes thus further supporting capacity building in the area.

Social events: In order to further enhance active interaction and networking between students and lecturers as well as amongst students, a rich programme of social events was included. Several participants had still the energy to to participate after a long, loaded day in the social events organised every evening and took advantage of the offered networking opportunities. These online social events were based on the specialised SpatialChat [23] platform which offers numerous possibilities to facilitate interactions simulating real-life conditions of groups of participants who, discussing with a wine glass at their hand, would move around from one group to another, from one "room" to another. The creative core team of students, helping with all practical items of the school, fully exploited the SpatialChat characteristics and offered an impressive online environment implementing an interesting programme.

FIG. 3. Architects design of the SEEIIST next ion cancer therapy research facility (courtesy "Kaprinis architects").

A dedicated colourful poster for the evening social events announced the daily programme that included from Monday to Friday: (a) Welcome drinks: giving the opportunity to meet all attendees breaking the ice while getting introduced to the ENLIGHT network by its coordinator. (b) Language café: giving the opportunity to chat about the different cultures of participants, their favourite traditional foods and drinks while reflecting, after a presentation based on statistical data, on the status of cancer-health conditions in their region and possible improvements that they could contribute in the future. (c) Students Q&A: providing the chance to the students to ask questions and seek advice while they were stimulated by the activities discussed by the CERN Knowledge Transfer experts. (d) Tours Games and Disco: providing the environment for entertainment during a "students'-only day" and opportunities for creating friendships and bonds sharing same interests not only at professional life. (e) Career Fair: the highlight of the social events, giving the opportunity to visit different stands organised by several institutes, including CERN, GSI, DKFZ, CNAO, MedAustron, Cosylab. Students had the chance to approach their experts, as in real-life open house events, and get informed of the opportunities offered by each one of these institutes, that spanned from research and medical heavy-ion treatment centres to companies (Fig. 4). In addition to the daily themes, including special drinks, food and entertainment, the social events programme was enriched by the additional touch of the "dress code" every day spanning from smart casual and formal attire to pyjama party. Participants certainly did the most out of it, to the great satisfaction of the organising team seeing their efforts being appreciated. Furthermore, participants suggested to include them during the coffee breaks also, which will be a great improvement for any future online or hybrid events. Indeed, the HITM school social events successfully combined entertainment with networking which is crucial for young students seeking guidance for their future studies and career but also for the specialised institutes to attract the most motivated students that are promising to become members of the heavy-ion therapy community.

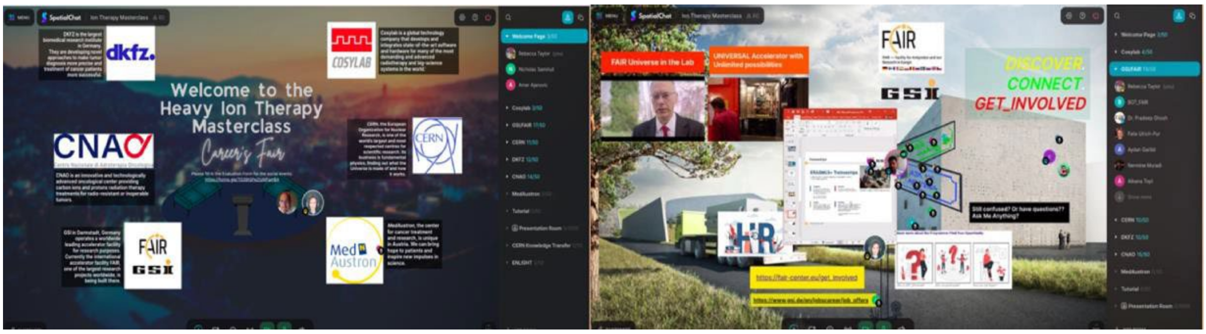

FIG. 4. HITM school social events and career fair in SpatialChat platform.

Networking: The worldwide reach of the HITM school demonstrates the increasing interest in heavy-ion therapy but also the power of networks. Networking is particularly crucial in the multidisciplinary field of heavy-ion cancer treatment to connect experts in different fields that are typically widespread around the globe. In that respect, the role of networking and the role of the ENLIGHT network in particular were detailed during the opening introductory presentation but also during the introductory drinks welcoming participants at the social events at the end of the first day. Furthermore, announcing the school through the ENLIGHT mail lists but also the International MasterClasses, IMC, mail lists, reflected in the worldwide participation to this school. As an example, the maps of Fig. 5 show the participation to the IMC and the HITM school that match almost one-to-one, since the school was announced through their network also.

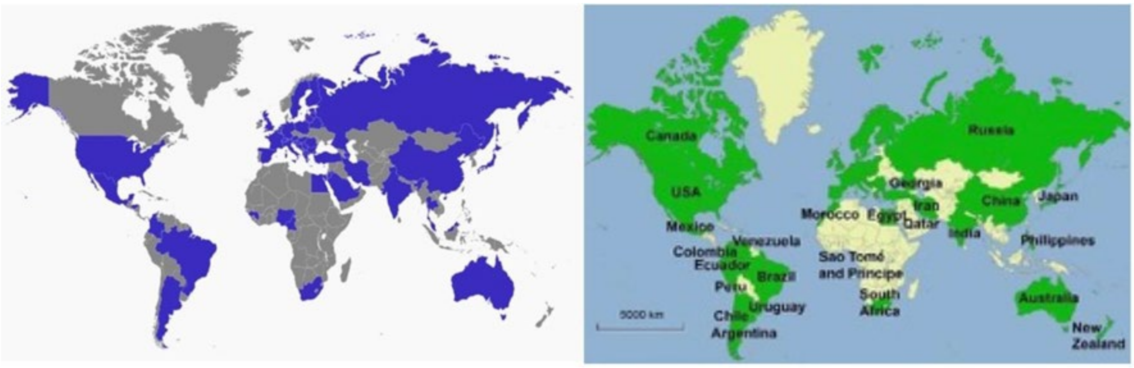

FIG. 5. World-wide reach of Heavy Ion Therapy Masterclass school (left) similar to the IMC programme reach (right).

Sustainability example: An IMC member from Benha University in Egypt contributed with an interesting initiative by integrating, formally, the whole week HITM school into the curriculum of the university and organised the participation of some 100 university students. Students from different faculties including physics, medical physics, medicine, engineering, agriculture, joined the lectures sessions from a single large auditorium, and the hands-on sessions from dedicated smaller computing lab rooms. Every day, they presented their hands-on results and impressed with the noticeable active participation of female students, a good example of diversity and sharing know-how in general. Noteworthy to mention that the dean not only provided full support, but he highlighted during the opening session the importance of this school that provided their students with the opportunity to participate to specialised courses delivered by leading experts (Fig. 6). Also, noteworthy to mention, the Benha University hosts the PTMC every year with a large participation of high-school students typically attracting over a hundred high-school students every year. Clearly the tutors had a great benefit and support from following the specialised courses of the HITM school.

FIG. 6. Opening session of the HITM school and participation of the Benha university of Egypt integrating the full week course in their curriculum.

Logistics: The platform for the online event was zoom which is convenient and already popular and widely used by several scientific communities. Naturally, the large number of zoom connections posed a challenge which technically was possible to overcome with the CERN expert support. However, it also presented a risk exposing participants to undesired experiences known as “zoom-bombing”. Therefore, the school started with a webinar style the first morning through which the zoom link was then provided to participants. In addition, a dedicated person from the core organising team was ready to react in case of undesired interventions. This clearly enhanced the possibilities for interactions with participants. To further facilitate interactivity, a shared document was setup where everybody could edit questions that were then answered by the lecturers verbally, while other participants could post further questions on the topic creating a thread. Based on this inventive mode of discussion a total of 450 questions were addressed during the week, as, apparently, the anonymity made participants feel more comfortable to ask questions. In addition, zoom chat and polls were heavily used to keep continuous interaction with participants and react promptly to their needs and requests. Polls, launched unexpectedly, were also used as means for verification that participants indeed followed up the lectures and were useful in the process of granting attendance certificates. Also, to facilitate the process, a dedicated google drive was provided where participants could upload their results from the hands-on sessions in their dedicated folders. This was also a verification, for granting them their "certificate of attendance". In order to remedy the difficulties posed by the different time zones (having participants from Latinoamerica to Australia) the presentations and recordings of the morning lectures were immediately available during the lunch break and of the hands-on sessions in the evening every day. Furthermore, surveys launched every day provided the means to participants to give their opinion and comments.

Statistics: Participants were literally from all over the world, almost equal numbers from European and non-European countries. The school had a good gender balance (Fig. 7) with about 18 female speakers out of a total of 36. In addition, it encouraged students' active participation which resulted in 25 students' presentations. Some of them were arranged in advance in the agenda; however, a good fraction of them was spontaneous, by giving the floor to the students in the students' sessions. The school covered overall 35,5 h, including 18 h of lectures, 7,5 h of hands-on sessions, 5 h of student sessions, and at least 5 h of social events that then run late in the night.

FIG. 7. Diversity and gender balance regarding female tutors and students.

Conclusions: The full-week HITM school addressing university students and the one-day PTMC addressing high-school students make them aware of the different aspects of heavy-ion therapy and of interesting career paths, in emerging fields, where often there is lack of specialised personnel, for example, accelerator physics, medical physics, biophysics etc. They also provide information about upcoming modern techniques for cancer tumour therapy with heavy-ions and new research avenues, where clearly the development of technology and the expertise of research laboratories is crucial. Based on the "train-the-trainer" sustainability model of HITM school, the expectation is that participants of the HITM school will become tutors for the next years PTMCs.

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REFERENCES

[1] HITM school webpage: https://indico.cern.ch/event/1019104/

[2] HITRIplus project webpage: https://www.hitriplus.eu/

[3] Particle Therapy MasterClass webpage: https://indico.cern.ch/event/840212/

[4] ENLIGHT network webpage: https://enlight.web.cern.ch/

[5] CERN Courier webpage: https://cerncourier.com/

[6] CERN webpage: https://home.cern/

[7] GSI webpage: https://www.gsi.de/start/aktuelles

[8] SEEIIST webpage : https://seeiist.eu

[9] Graczykowski L., Nowakowski P., Foka P., *New developments for ALICE MasterClasses and the new Particle Therapy MasterClass*, in Proceedings of CHEP 2019

[10] Foka P., Particle therapy masterclass, Proceedings of EPS-HEP European Physics Society conference on High Energy Physics, 26-30 July 2021, online, to be published

[11] Foka P., Mamaras A., et al, Particle therapy masterclass, PoS Proceedings of vCONF A Virtual Tribute to Quark Confinement and the Hadron Spectrum Conference, 2-6 August 2021, online, to be published.

[12] UNSA webpage: https://www.unsa.ba

[13] IMC webpage: https://physicsmasterclasses.org/

[14] DKFZ webpage: https://www.dkfz.de/en/index.html

[15] matRad – an open-source dose calculation and treatment planning toolkit, https://github.com/e0404/matRad https://doi.org/10.5281/zenodo.3879615

[16] 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. https://doi.org/10.1007/978-3-319-19387-8_391

[17] Wieser, H.-P., Cisternas, E., Wahl, N., Ulrich, S., Stadler, A., Mescher, H., Müller, L.-R., Klinge, T., Gabrys, H., Burigo, L., Mairani, A., Ecker, S., Ackermann, B., Ellerbrock, M., Parodi, K., Jäkel, O. and Bangert, M. (2017), *Development of the open-source dose calculation and optimization toolkit matRad.* Med. Phys., 44: 2556-2568. https://doi.org/10.1002/mp.122Mairani 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. https://doi.org/10.1007/978-3-319-19387-8_391

[18] D. Craft, M. Bangert, T. Long, D. Papp, J. Unkelbach, *Shared data for intensity modulated radiation therapy (IMRT) optimization research: the CORT dataset*, GigaScience, Volume 3, Issue 1, December 2014, 2047–217X–3–37, https://doi.org/10.1186/2047-217X-3-37

[19] CNAO: https://fondazionecnao.it/en/

[20] Haberer T., et al., Magnetic scanning system for heavy ion therapy NIM A 1993

[21] Bryant, Philip J, *PIMMS: Proton-ion medical machine study,* in CERN Yellow Reports: Monographs, ebook: 10.5170/CERN-2000-006

[22] HIT : https://www.klinikum.uni-heidelberg.de/interdisziplinaere-zentren/heidelberger-ionenstrahl-therapiezentrum-hit/

[23] SpatialChat webpage: https://spatial.chat