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More than 30 years of experience in fusion education at the Institute of Plasma Physics of the Czech Academy of Sciences

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Abstract

The complexity of making magnetic confinement fusion a suitable source of energy for mankind imposes long lasting investigations. To accompany these efforts, new generations of physicists have to be trained over the years to ensure continuity of the research. These scientists must have very versatile profiles as fusion inquiries are multiphysics (magnetohydrodynamic, plasma-wall interactions, cutting edge technologies...) and require skills in both experimental and theoretical physics. The Institute of Plasma Physics IPP Prague of the Czech Academy of Sciences (IPP Prague) has contributed to the education and training of a non-negligible number of students in this area, one reason being the good accessibility of its fusion facility, the other being its strong connection with universities. This article shows the views and achievements of IPP Prague on education. In particular, we insist on the fact that to keep students in the field they have to be acquainted with practical plasma physics as early as possible (on the bachelor level if possible). We also show that a strong integration of PhD candidates within the scientific staff is an important factor for their training and serves them to be autonomous. Last, we present two experimental 2 weeks training courses, called SUMTRAIC and EMTRAIC, that are annually organized by IPP Prague and that have acquainted more than 300 participants to the practical physics of tokamaks.

Keywords: training school, plasma physics education, education at the Institute of Plasma Physics of the Czech Republic

(Some figures may appear in colour only in the online journal)

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Introduction

With the fusion experiment ITER on the way and the substantial number of fusion devices under construction or in commissioning phase (JT-60SA, COMPASS-U, DTT...) in the world, the need for fusion scientists in the forthcoming decade is likely to increase. These scientists should be well trained and have not only a good knowledge of plasma physics but also of the concrete operation of a tokamak and diagnostics. In addition, training of these scientists is subject to an important time lag (from the first year of university to obtaining the PhD degree, there is at least 8 years) and needs to be addressed in a long term.

Several local programs in different countries have been created to teach fusion science and technology at the universities at master or bachelor levels. A joint European effort, called the European Master of Science in Nuclear Fusion and Engineering Physics program or Fusion-EP in short, has even been established to teach on the master level [7]. PhD students are generally enrolled at universities but working on existing fusion devices in laboratories in order to get practical experience. Again, a European effort, called joint doctoral programme in Nuclear Fusion Science and Engineering or in short Fusion-DC, was also created to coordinate European wide PhD theses, however, recently terminated (end of European funding). In different countries with doctoral fusion programs, the proposed PhD topics are highly connected to the available devices and it is easily understood that large devices with complex access procedures cannot easily offer experimental topics to young students, which consequently focus more on data analysis, theory development and simulations. The role of smaller devices, i.e. more accessible, is therefore very important to form scientists with a strong expertise in experimental physics.

The tokamak department of the Institute of Plasma Physics of the Czech Academy of Sciences in Prague (called IPP Prague in the text) was, and is still, able to contribute to this worldwide effort. Equipped originally with the small CASTOR tokamak in 1977, later replaced by the middle size COMPASS tokamak in 2009 (see section 1 for more details), IPP Prague offered a wide variety of experimental topics at different educational levels (bachelor, master and PhD), contributed to the development of new diagnostics and even taught a significant number of young PhD students how to operate a relevant fusion device. On the European level, IPP Prague is one of the funding members of the European Fusion Education Network [12] and takes an active role in holding a winter school for the Fusion-EP master (see below EMTRAIC).

This article tries to summarize our long lasting efforts and experiences with education and training of new generations of fusion scientists. In particular, we show how important is the strong integration of PhD students into the research team, in our views, and we describe in detail our two renowned experimental 2 weeks training courses that can surely inspire other facilities. The presented strategy plays, we believe, an important part in the significant growth of the tokamak department in the past 15 years.

The structure of the paper is as follows: at first, in section 1, we briefly describe the history of fusion research in the Czech Republic and its main tokamak in operation, called COMPASS. Section 2 presents how education of local students is organized at the tokamak department of IPP Prague. We illustrate in detail how undergraduate as well as PhD students are attracted to fusion science as well as the collaborations with one of the Prague universities. Section 3 is devoted to the description of two very original training courses organized annually at IPP Prague since 2003. A particular care is given to describing all the know-how and details.

1. The Institute of Plasma Physics of the Czech Academy of Sciences

1.1. A brief history of fusion research in the Czech Republic

The plasma/fusion physics has been investigated at IPP Prague since 1959. At the time, several experiments on interaction of magnetized plasmas with electron beams and radiofrequency waves were accompanied with relevant theories and modelling efforts. An important breakthrough happened in 1977, when a small Soviet tokamak (called TM-1-MH back in USSR) was moved to Prague and successfully put in operation. A special department, called the tokamak department, was then created around it. Experiments on this device (that was later re-named CASTOR) continued until 2007. However, at the early age, there was a lack of experienced plasma physicists, in particular until 1989, namely because of the limited number of available positions, mostly due to financial reasons. During that period, the CASTOR tokamak was operated by 9 experimentalists (among which 7 were PhD candidates) accompanied by 4 theoreticians (all PhDs) and their average age was well above 40. Later on, the change in the political as well as financial situations in the 1990's broadened the possibilities to enlarge involvement in fusion research in the Czech Republic and the tokamak department grew gradually over the years.

A second important breakthrough happened in 1999, when the Czech Republic was associated to the European Atomic Energy Community (EURATOM). After that, the research on CASTOR became more visible within European fusion laboratories, and more and more international collaborations were initialized. Since this time, a major reflection started at IPP Prague on how to systematically educate and train the new generations of fusion physicists and actions, that are described in the following sections, were taken. The possibilities of practical training, together with scientific investigations, in experimental fusion research increased again in 2006, when a larger tokamak, COMPASS, brought from UK, replaced CASTOR. From this moment, two tokamaks are available in the Czech Republic, as the CASTOR tokamak was moved to the Faculty of Nuclear Science and Physical Engineering (FNSPE) of the Czech Technical University (CTU) in Prague, and (for the second time) renamed to GOLEM. At the time of writing, the COMPASS tokamak is still in operation, but will, however, be replaced soon by a new tokamak, called COMPASS-U, currently under design at IPP Prague.

In short, the thorough educational and training efforts that started after 1989 at IPP Prague and that increased significantly with the arrival of COMPASS in 2006 continue mainly in two directions:

- strengthening the link between the tokamak department of IPP Prague and Prague universities, in order to attract and educate new students,
- the practical training of Czech as well as foreign students in tokamak operation in two experimentally-oriented schools, which started at CASTOR in 2003, and continue on COMPASS till now.

Before presenting these two aspects of education at IPP Prague, let us first introduce the main experimental facility in operation in Prague, the COMPASS tokamak.

1.2. The COMPASS tokamak

The IPP Prague has been operating the COMPASS tokamak since 2006 when this device (named COMPASS-D at the time) was taken over by the Czech Republic from UKAEA, Great Britain. Its main mission is to contribute to the worldwide effort in the realization of future fusion reactors and, in particular, contribute to engineering and physics scaling laws towards the ITER tokamak [11]. When moved to Prague, IPP Prague and EURATOM agreed that the

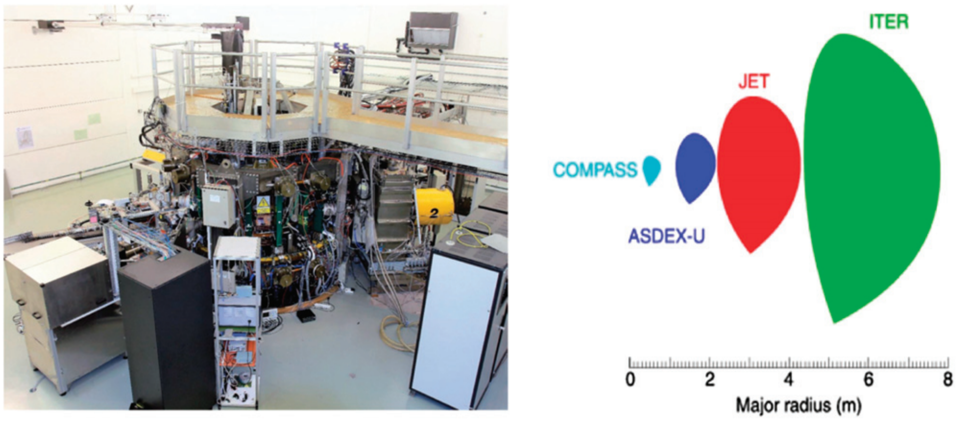

Figure 1. Left—picture of COMPASS in the IPP torus hall. Right—plasma cross section of COMPASS compared to large European tokamaks with ITER-like plasma cross-section.

device will serve both for research and education purposes, hence the strong efforts that IPP Prague put in educating since that time.

COMPASS is a small/middle sized tokamak with major/minor radii of 0.56/0.2 m, the toroidal magnetic field can reach up to 1.8 T, the plasma current is up to 400 kA, and the pulse length is up to 1 s. COMPASS is equipped with two additional plasma heating units (two neutral beam injection systems). The tokamak operation in advanced discharge regimes such as the ELMy H-mode [1] or detachment [14] are routinely achieved, showing the high relevance of the research towards ITER. A sophisticated set of plasma diagnostics allows detailed studies, focused in particular on edge plasma physics [2]. A picture of COMPASS in the torus hall (left) and a comparison of its size with other fusion facilities and with the ITER-like plasma cross-section (right) is shown in figure 1.

The COMPASS plasma cross-section has a similar shape to ITER and, therefore, it represents an important element of the so called European step-ladder approach together with several other existing European facilities, as the two ASDEX-U and JET tokamaks (see figure 1). Each device of this ladder serves to establish scaling laws that are extrapolated to predict the optimal parameters of future and larger fusion devices, like ITER [17]. Fusion research on COMPASS is fully integrated into the joint European efforts in realization of the fusion energy under the umbrella of EURATOM/EUROfusion, resulting in strong international collaborations.

After more than 10 years of the COMPASS operation, the tokamak will be soon replaced by a new device (called COMPASS-U), with a goal to significantly contribute to solutions of the key challenges of the ITER and DEMO projects [3]. COMPASS-U will be a medium-size tokamak operated at a toroidal magnetic field up to 5 T, with pulse duration up to 10 s, plasma current up to 2 MA and flexible magnetic configurations with closed divertor, double null configuration... COMPASS-U commissioning is planned in 2023. It is clear that COMPASS as well as COMPASS-U require an extensive and experienced team of plasma physicists and engineers.

Table 1. Affiliation of the undergraduated students involved at IPP Prague at the time of writing, showing the strong connection of IPP Prague with Czech Technical University (CTU).

Affiliation of undergraduate students	Numbers
FNSPE-CTU	12
Other universities	6
Total	18

2. Education at IPP Prague: from bachelor to PhD degrees

According to our long term experience (about 30 years), students that would stay in the domain of fusion have to be attracted already during their bachelor and master studies at the university. Therefore, education of new generations of engineers and physicists at IPP Prague is handled by having strong interconnections with Prague universities, where plasma physics lectures are given. Despite PhD titles can only be delivered by universities in the Czech Republic, several PhD students perform their research activities in laboratories external to universities: it is thus crucial to keep a lively connection with Universities and to advertise all the research topics suitable for a PhD thesis. This section describes how IPP Prague gets in contact with students from the very beginning of their studies and integrates them gradually to the scientific team.

2.1. Bachelor/master students: acquainting a new generation with fusion science

The IPP Prague is in contact with several universities in the Czech Republic (the Charles University in Prague, the Masaryk University in Brno) and in Slovakia (the Comenius University in Bratislava), but the main source of its students comes from the CTU in Prague. For instance, more than two thirds of the undergraduate students currently involved in the tokamak department are coming from CTU as can be seen from table 1. We therefore concentrate here on the relationship between these two institutions.

At CTU, most of the lectures are taught under the curriculum named '*Physics and technology of nuclear fusion*', that aims at training students at the first year of university up to the master level. The covered subjects are plasma physics, mechanics, electricity and magnetism, waves and optics, thermodynamics, theoretical and experimental physics as well as applied physics and advanced mathematics. Up to 20 students are following the curriculum every year. Since that curriculum is very demanding, about 6 of them make it to the master level only. We will not describe in more details the educational courses at CTU as more information will be provided in a separate article in this same journal [6].

First of all, let us mention that the strong connection between IPP Prague and the CTU is easily illustrated by reminding the reader that the CASTOR tokamak, now renamed as GOLEM, was donated and transferred from IPP Prague to CTU. This action made Prague as one of the only cities in the world hosting two fully operating tokamaks and it provided the university with a unique tool for educating students, while also performing scientific investigations. Thanks to this, CTU is able to offer fusion relevant topics already at the bachelor and master levels. However, since the staff of GOLEM is rather limited (one senior scientist and one part time technician), it is not rare that team members of IPP Prague supervise or co-supervise bachelor and master theses on topics related to GOLEM activities. This is a very good chance for students to work with scientists from the very beginning of their studies and it allows IPP Prague to discover future talents that could be offered a master or PhD topic, later on. Obviously, not every country/university has the capacity of operating a small tokamak but any relevant plasma physics device could serve the same purpose. It is worth mentioning that this strategy is also investigated at the CTU, where the creation of a plasma lab with several 'simple' plasma devices has been initiated with help of European structural funds (see the forthcoming article on CTU [6] for more insights on that matter).

In addition, since the number of CTU students can be higher than the capacity of GOLEM, IPP Prague also offers topics directly linked to the COMPASS tokamak. In fact, among 34 CTU students that followed the aforementioned CTU plasma curriculum, 22 bachelor and master theses were COMPASS oriented. Very often, the students start as bachelor and continue their topic (which becomes more complex and scientifically relevant) as master. This is also a very good way of attracting and keeping fresh blood. Of course, it is more handy for middle size tokamaks like COMPASS, which are quite flexible in terms of planning experiments and assuring a direct contact of the scientists with the device, but the authors believe there are always ways of proposing topics to students even on larger devices. For instance, IPP Prague is willing to keep this strategy for COMPASS-U, even though it will be a less flexible device than COMPASS (more complex tokamak with cryostat, higher parameters...). Obviously, the proposed topics to students, usually quite experimental on COMPASS, will have to be adapted and be more oriented towards data analysis but offering topics to students should still be possible. Last important point, since the students get acquainted with COMPASS at an early age, it is a big plus for those that want to continue a master or PhD at IPP Prague, as they are very familiar with the machine, the team and the CODAC (Control, Data Acquisition and Communication) system. It helps them integrate to the team quickly and we have observed that many of them took rapidly important roles (operators of the tokamak, diagnostic specialists etc…) even before completing their studies (see the PhD section for more details). This has proven to make IPP Prague a very dynamic place and can partially explain its rapid growth in the past 10/15 years.

2.2. PhD education: strong integration of the students into the research team

2.2.1. The university in the Czech Republic, an essential actor in PhD education. The PhD curriculum in the Czech Republic being somehow different from what PhD programmes are in other countries, we will first describe it to put into context what can be useful for scientists over the world that would like to apply similar methods. By law in the Czech Republic, the responsibility for fulfilling the doctoral training programme and awarding the PhD degrees relies with the Czech universities. Therefore, PhD studies are always organized under the umbrella of an university.

The system of PhD study is the same for all state universities. Universities must hold an accreditation by the Ministry of Education, Youth and Sports, for each field of doctoral study, which may encompass several programmes. In total, doctoral students are obliged to pass an equivalent of approximately 16 ECTS in the advanced courses before being admitted for a committee (state, rigorous) examination. This examination typically happens at the end of the first or the second year of doctoral studies, after which the student has no other obligations to the university than working on his dissertation, including reports, presentations and journal publications. Participation in undergraduate teaching is not required, but it is encouraged. Doctoral students are entitled to some governmental scholarship for the maximum duration of four years, however many of them are also contracted for part-time research in a field close to the subject of their doctoral thesis, and not many of them finish their studies (i.e. defend their PhD thesis) by the end of the fourth year as normally requested. It means, and this is a peculiar point regarding PhD studies in the Czech Republic, that a PhD can in principle last from 7

Table 2. Sources of PhD students currently studying at IPP Prague.

Universities	#
FMP, Charles University in Prague	7
FNSPE, CTU	8
Foreign PhD student	1
Faculty of Mechanical Engineering, CTU	1
Total	17

to 9 full years, depending on the university, compared to most countries where PhD are to be accomplished in 3 or 4 years.

Currently, IPP Prague has two official partner universities:

- Faculty of Mathematics and Physics (FMP), Charles University in Prague. In particular, the Department of Surface and Plasma Science organizes the doctoral program 'Physics of Plasma and Ionized Media' since the nineties.
- Faculty of Nuclear Science and Physical Engineering of the CTU in Prague since 2015, already mentioned in the previous paragraph. A new accreditation for fusion physics has been approved for the next ten years, i.e. 2020–2030. In addition, a new agreement for joint PhD programme between CTU and Ghent University in Belgium has been signed recently.

2.2.2. Generalities about PhD education at IPP Prague. The IPP Prague can attract new PhD students in fusion physics by proposing topics of thesis that should be supervised by a COMPASS researcher. The faculty nominates an accredited consultant of its own staff to assure a closer link between the faculty and IPP Prague. This is usually a win/win collaboration for the three parties: the student, that gets to work on a real fusion device with an experienced team and still with some valuable lectures at the university, the faculty that can offer a wider range of PhD subjects and facilities, and IPP Prague that can attract new young scientists that, later on, can join the team.

Illustrating the importance of PhD students for IPP Prague, let us mention that there are 17 PhD students currently performing their PhD studies at the tokamak department (see table 2). As evident from the following table, a majority of them are recruited from CTU, mainly because of what was explained in the previous section.

2.2.3. The IPP Prague strategy on PhD education. The main peculiarity of PhD education at IPP Prague is the strong integration of PhD students into the scientific team and their involvement in the research programmes. PhD candidates are, of course, still considered as students but they are pushed to be proactive members of the team and their research work is usually not strictly bounded to their PhD topics. For example, a student, whose topics is on the design and development of a diagnostic on the COMPASS tokamak, will also actively take part in the experimental campaigns for which the diagnostic would bring valuable outputs. The students will thus participate in the campaign planning and should, therefore, understand the ins and outs of the relevant physical studies. This allows them to diversify their knowledge and it makes them more versatile. In addition, they are also responsible for installation of their diagnostic on the machine and to do it by themselves, helped by the responsible vacuum technicians. Another standing example is the fact that some selected PhDs are trained as operators of the COMPASS tokamak. This is a very strong asset for those students and gives them a deeper understanding of fusion science and technology: the operator controls and sets the discharge parameters, but also discusses the impact of their changes on the plasma behavior with the scientific team in charge of the experimental campaign and, thus, gets involved in the research investigations.

Thanks to this substantial participation of PhD students in the research activities of IPP Prague, it is not rare to see some of these students become main investigators (planning their own experimental campaigns, selecting the diagnostics needed etc...) of some highly relevant fusion research topics. At the end of their studies, an IPP Prague PhD candidate has already acquired significant experience, both in science and engineering, and is very well trained to conduct his own independent research, with very little need for supervision. This long term investment is of course facilitated by the fact that PhD students in the Czech Republic can pursue their studies over a long time (to a maximum of 7–9 years as already evoked), allowing them to both spend time on their thesis and on the extra work (for which they are paid for) at IPP Prague. However, it clearly shows the strong asset for the fusion community of having medium size tokamaks with flexible scientific programmes for the formation of very versatile and skilful students. This strategy is also very profitable for IPP Prague as it possesses resources to employ the students after they graduate (accounting for the fact that students are already partially and fully paid by the institute at the end of their studies). Therefore, and it is especially true with the fact that the IPP Prague staff has almost tripled in the past 10 years, most freshly graduated PhD students are employed by the IPP Prague, few go abroad and almost none leave fusion science. To our knowledge, they are very few European institutions that can offer to keep most of their students after graduation.

In addition to the aforementioned point, PhD students have to present their recently achieved results or investigations at seminars of the department, to make rehearsals... as well as to participate in international conferences, similarly to what is done in most fusion laboratories in Europe. The COMPASS tokamak being part of the European effort in fusion research in the frame of Eurofusion, PhD students often participate in medium-sized tokamak (MST) activities [5] on other European devices, having the chance to broaden their views and make more acquaintances in the field. Last but not least, PhDs frequently become supervisors of bachelor and master thesis of university students (see the previous section on that topic), which help them in developing their teaching skills.

3. Renowned training courses organized by IPP Prague

3.1. Introduction

In European fusion education, IPP Prague is unique in the community as it has been hosting two annual student workshops: one called SUMTRAIC (SUMmer TRAIning Course) for more than 15 years and one called EMTRAIC (Erasmus Mundus TRAIning Course) involving master students from the Fusion-EP master [7]. Both workshops are two weeks events (one at the end of August, beginning of September, usually, the other one in December) and aim at showing and teaching students what a real scientific researcher does. Indeed, during the two weeks, students receive a scientifically relevant subject and, under the supervision of a staff member of IPP Prague, participate in the experiments and must analyze real data. It is quite different from other winter/summer schools that are organized in other countries, where mostly theoretical lectures are given. Let us now describe in detail the SUMTRAIC event. The EMTRAIC school is described after, though very similar to SUMTRAIC, as it shows how such events can be implemented in the university’s curriculum.

Table 3. Typical program of SUMTRAIC. In bold, topics fitting the experimental plan (note that these were real SUMTRAIC topics), underlined lectures to the students and, in italic, social events.

Date	Day	Morning	Afternoon
28.8.	Monday	Introductory lectures	Introductory lectures
		Discussion with supervisors	**Zonal flows investigation**
29.8.	Tuesday	Lecture about Czech habits & culture	*Welcome party*
30.8.	Wednesday	**Shoulder formation**	**ITER VDE/disruption**
31.8.	Thursday	**Detachment**	**Heat flux measurements**
1.9.	Friday	**Error field correction**	Data processing
2.9.	Saturday		
3.9.	Sunday	*Tour in Prague*	*Tour in Prague*
4.9.	Monday	Data processing	**Experiment - contingency**
			Data processing
5.9.	Tuesday	**Experiment-contingency**	Lecture on how to become a scientist
		Data processing	
6.9.	Wednesday	Lecture on how to make a presentation	Preparation of presentation
7.9.	Thursday	*Visit of the GOLEM tokamak*	Preparation of presentation
8.9.	Friday	Closing workshop	Closing workshop

3.2. SUMTRAIC event

3.2.1. General description. The idea to organize practical training of students on a tokamak has appeared in 2002, when representatives of two EURATOM associations (Czech Republic and Hungary) felt the necessity to educate a new generation of plasma physicists. It was therefore decided to organize jointly a two weeks practical training on the, back then, CASTOR tokamak at IPP Prague (now called GOLEM and operated at the CTU). The first event, that was already named SUMTRAIC, was held in 2003 and students were exclusively from Hungary. Since that time, the structure of the two weeks annual SUMTRAIC event has been kept as follows (see table 3) with minor changes and improvements over the years. The first day (Monday) is devoted to lectures (see table 4) introducing the tokamak facility, safety rules, and access to the tokamak database etc... Then, students are divided in several experimental groups according to the experimental tasks previously selected by the organizers and based on the operational plan of the tokamak department. Each group, composed of one, two (usually) or three students, is supervised by one or two experienced scientists from IPP Prague staff. Students participate in tokamak experiments and data processing during the next 8 working days. The main aim of the event is to get students in touch with the tokamak reality and to teach them almost all aspects of experimental research on tokamaks, i.e.:

- take part in measurements according to the experimental programme of the facility,
- process experimental data,
- discuss results within experimental groups, with their supervisors and with the scientific staff,
- prepare presentation on experimental results,
- and finally, present their achieved results on the closing ceremony of the workshop, in front of the scientific staff of IPP Prague and the other participants.

In general, the experiments are realized during the first week of SUMTRAIC to collect a sufficient amount of experimental data for the students to work on, and for them to get enough expertise with tokamak performances. The second week is more focused on data analysis and

Table 4. Typical Monday introductory lectures at SUMTRAIC. The number of lectures is reduced as much as possible in order to allow students to work on their topic as long as possible.

Time	Topics of the lectures
09:30	Opening ceremony and presentation of the programme and topics
10:00	Tour around the facility (visit of the tokamak)
11:00	Access to the tokamak database (login)
11:10	Introduction to the data acquisition system and the COMPASS database
11:30	Organisation of the COMPASS logbook
12:00	Lunch
13:30	Lecture about tokamak physics and COMPASS tokamak
15:00	Introduction to Python
16:30	First discussion with supervisors

contingency experimental days are reserved for the groups still lacking data or that can continue the experimental analysis further. Since the reinstallation of the CASTOR/GOLEM tokamak to the CTU, participants usually visit this facility at the faculty during one morning session. The closing ceremony takes place on the last day. Each experimental group prepares a common presentation, but every student in the group has to present a part of it (usually during 10 minutes). It has to be emphasized that this is very often the first presentation in their life (and in English). Each presentation is followed by a short session (5/10 minutes) of questions, discussions and comments on the students' work. Usually, the best three speakers are awarded by a symbolic prize. In the end, all attending participants obtain a certificate of their attendance.

3.2.2. Advertisement of the event. The call for participation to the SUMTRAIC event is announced half a year in advanced on the web page of IPP Prague [4] and on an indico based web page [8, 9], where students can find basic information about the event and fill a registration form (CV, motivation and reference letters...). Further advertisement is made by the organizers by contacting foreign colleagues via email or during conferences. It is to be mentioned that, the event being very appreciated by the students, newcomers often heard about SUMTRAIC from former participants.

3.2.3. Request information from the students. The main information students should provide are a CV, a motivation and a reference letters, which are to be communicated to the organizers through the indico website (see the 2019 webpage of SUMTRAIC [9]) or by email. These documents serve to select the candidates as well as for statistics purposes. Students have also to provide their names, email address, nationality, country, sending institution (if relevant), and eventually passport number and personal address (if invitation letter for visa application requested). As the event aggregates a non negligible number of students (up to 16) from very different countries and, thus, cultures, it is from our experience important to ask the students for special food regimes or conditions and students are invited to inform the organizers about any special request they may have.

3.2.4. Student selection. Interested students have two months from the start of the call to apply for the event. Acceptance is approved by organizers about four months before the event, which gives plenty of time for students to ask for visa if necessary (IPP Prague in that case provides an invitation letter and proof of acceptance). Number of accepted students is limited, generally not exceeding 16 students, and depends on IPP Prague capacity. The selection of students is mostly based on

- the motivation of students, the event being open to any students from bachelor studies to PhD studies (on special cases, scientific researchers can also participate) that would like to get acquainted with experimental operation of a tokamak machine,
- correct filling of the form as students have a tendency of not doing so (many applications can be rejected on the form filling quality),
- recommendation letter,
- interesting profiles, i.e. cross-field students, students belonging to universities/laboratories with which IPP Prague is collaborating…,
- in case of a high number of applicants: level of English and programming are a plus. Physics background is also evaluated regarding the COMPASS experimental plan.

In general, no discrimination in education levels is made and slots for third world countries or countries where fusion education is not taught are opened. Most of the selected students are usually coming from outside of the Czech Republic and a non-negligible part from outside the European Union. The selection also tries to keep a gender balance but very often the number of women does not exceed 20% of the participants, due to the lack of application and interest of women in the field.

3.2.5. Topic selection and assignment. The number of topics depends on the number of selected students, the operational plan of the tokamak department and available supervisors. Proposed topics are always scientifically relevant topics in the field. In general, this is a long process selection and requires the organizers to be acquainted with the scientific topics studied by their colleagues and the experimental timeline. There is no specific recipe on how it is handled and it is therefore based mostly on communications and long discussions. In addition, they are clearly two main components without which the event could not take place which are: a strong support of the management and a high motivation of the scientific staff for supervising students. Since they are usually up to 8/9 groups and since the goal of the event is to acquaint participants with experimental aspect, the experimental plan is, if possible, organized in such a way that several half days or one day topical studies are performed in the first week, to provide as many experimental topics as possible. However, it often happens that not enough experimental topics are available and that students have to work on already existing experimental data. Even in this case the students can experience some of the crucial phases of a fusion experiment and can have access to real data analysis.

The assignment of topics is decided by the organizers without consulting the students. This is done to avoid complexification of an already quite complex process. This has proven to work very well and almost no complains from students were ever registered (see the feedback section). If possible, the subjects are announced prior the event takes place and students may have the opportunity of swapping a subject for another, but it is extremely rare, on specific demands only, and requires agreement of other students with whom they are swapping. Regarding the assignment itself, it should account for external factors, that cannot always be foreseen, as for instance the level of the students in the group in programming, in physics, in presenting, their ability to communicate.… In general, high level topics are assigned to students with knowledge in the field and/or on the PhD level, a skilful programming student is always paired with a less good programming one, and simplified topics are sometimes made up for beginners. Last, students are in general assigned to topics not related to their field of studies, unless they are at the really beginning of it, in order for them to learn something new. For instance, a student doing his PhD on Langmuir probes is preferably assigned to a topic not dealing with this diagnostic.

Ensuring that students of different levels can all experience the main aim of the event (getting to know all aspects of being an experimental physicist) is left to the supervisors of each group, as it would be demanding for the organizers left alone. If some groups are still having difficulties in handling their subjects (too complex, lack of programming skills…) during the second week of the event, more time is devoted to them from their supervisors or, even, the organizers, to help them going through. The preparation of the final presentation also helps the organizers to detect groups in difficulties and to spend more time with them. It is to be mentioned that struggling with his/her research is also a part of an experimentalist's job and that the students should experience those difficulties too, as part of their learning.

3.2.6. Plenary lectures. The goal of the event being to get students acquainted with the experimental aspect of tokamak physics, the number of lectures is kept as low as possible and fits in one day (first Monday, see table 3). In the morning, students are first introduced to their topics and mentors and asked to present themselves (names, countries, studies, interest in fusion…). Then, follows a visit of the facility and the tokamak for them to get acquainted with the experimental apparatus. The rest of the morning before lunch is devoted to lectures granting them access to the database and how to reach the right data. In the afternoon, a more thorough lecture about tokamak physics, with a special focus on the COMPASS tokamak, is given. Then, and this is quite recent and has shown to be very useful, an introductory lecture of about 1h 30 about the scientific programming language Python is given, with practical examples using real signal data. All these lectures are usually sufficient for the participants to work at COMPASS and the rest of information they would require is provided within the experimental group by their supervisors.

Last but not least, a short presentation (about 10 minutes) on how to make a good presentation was also introduced recently and is taught two days before the students' final presentation. It shows some basic things that students need to know to make a good presentation (for example how to deal with text colors, fonts, how to present a graph in an understable manner etc…), which is a very important guidance for these students as very often they are presenting a scientific work in front of an audience for the first time. The presentation is open for discussion and students are generally very interested, ask a lot of questions and give their personal opinions on how they think presenting should be done. This exchange time is profitable for their future career, if they stay in the research community, and has been placed just before students start working on their final presentation, to maximize their interest.

3.2.7. Data analysis. Mainly three programming languages are used at IPP Prague Prague (Python, Matlab and IDL) and made available to the participants. Often, the language used within the experimental group is homogeneous (the same for all the students in the group) and matches the one of the supervisors, but it is not a general rule. In addition, the number of licenses of Matlab and IDL being limited within the institute, students are pushed to use Python since a couple of years and the introduction of a general lecture about this language has proven to be very useful in this respect. The introduction of a web interface allowing to open a remote Python jupyter notebook (called jupyterhub, see [10]) on IPP Prague server through a standard browser (via standard LDAP user authentication) has also allowed students to work more freely and away from IPP Prague network (it can be launched from their own laptops, tablets, smartphones…) and has decreased the work station demand during the event.

3.2.8. Accommodation in Prague. The hotel booked by the IPP is located at walking distance from the tokamak department to allow students to work in the institute over standard working hours, and therefore be easily/longer time connected to the tokamak database.

3.2.9. Social events. According to our experience, an essential part of the training school are social events. This aspect should not be neglected, especially since some of these students can become (and some of them indeed became) our future colleagues. The most important one is the so-called welcome party that is organized at the beginning of the first week (usually on Tuesday, see table 3) in the premises of the tokamak department. It is an excellent occasion for participants to socialize between themselves and, what is even more important, with their supervisors. A second informal social event is often organized during the second week, downtown in a restaurant. A tour in the city of Prague given by the organizers during the week-end is also proposed to the students. This is on request and depends on the availability and good will of the organizers during the week-end. Since the CTU of Prague is equipped with the tokamak GOLEM, a morning session is reserved for the visit of this facility. Last, a special lecture on Czech culture, habits and language has been introduced recently to help the participants in their activities outside the frame of the event. This is generally appreciated by students and it becomes a game for them to order food in the restaurant in Czech after what they have learned from that presentation.

3.2.10. Financial arrangements. Usually, the hotel accommodation of participants is covered by IPP Prague. In the last four years, a grant from the Czech Academy of Sciences has served to cover these expenses and even to provide participants with per diem allowances. In the budget, it is to be mentioned that the operational costs of the tokamak and salaries of the supervisors and technical staff are covered by the institute. The travel costs of participants have to be handled either by their home institutions/universities, either by themselves. In the last years, a fee of 50 euros per participant was introduced and was due before the beginning of the event. This was done to secure the venue of participants.

3.2.11. Statistics and feedbacks. Since 2003, the Institute of Plasma Physics of Czech Academy of Sciences has organized 16 SUMTRAIC training schools. First four of them took place on the CASTOR tokamak. Because of its shut down and installation of the COMPASS tokamak at IPP Prague, next two training courses took place in Budapest at the University of Technology and Economics. From 2009 until 2019, SUMTRAIC returned to IPP Prague and experiments were performed on the COMPASS tokamak, excluding 2016, when the dates of SUMTRAIC collided with the SOFT 2016 conference held in Prague and had to be cancelled. In 2020, SUMTRAIC was cancelled due to travelling restriction happening worldwide.

As evident from table 5, more than 200 students from 30 countries were trained in experimental research at IPP Prague. Most of the participants were from Hungary, because our Hungarian colleagues were co-organizers of SUMTRAICs, especially interested since there is no tokamak in operation in their country. A large number of Czech and Slovak students have also been trained, and many of them became important members of the COMPASS team later-on. Note also a significant number of participants from non-European countries, who have got first touch with real tokamak experiments.

During all these years, the participants gave feedback on the event and suggestions how it could be improved. From the event structure described above (that evolved over 16 years and is now very mature), no major complains were recorded and, since the beginning, the event seems to be very appreciated by the participants.

3.2.12. Legacy of SUMTRAIC. The success of the SUMTRAIC event first inspired the FUSION-EP [7] coordinators to create a similar event but for the students of the master (see next section about EMTRAIC). It has also inspired other countries afterwards, see here a non exhaustive list:

Table 5. Number of students per year and per countries for all the 16 organized SUMTRAICs.

	Countries	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2017	2018	2019	Total
1	Austria		1		1									1				3
2	Brazil			3								1	2					6
3	Belgium		1					1	1	1	1	1					1	7
4	Bulgaria		1					2		2	2	2	2	2				13
5	Canada			2														2
6	Czech Rep.		1	1	2			6		2	1		1		1	2	1	18
7	Costa Rica													1				1
8	Estonia		1			2												3
9	Egypt		2	1														3
10	France							1					1	1		1		4
11	Germany														1			1
12	UK								4		2						2	8
13	Hungary	8	2	2	7	3		4	3	2	2	3	2	1	6		1	46
14	Italy				1								1		1		2	5
15	Iran			1													1	2
16	India																1	1
17	Netherlands															1	1	2
18	Norway				1													1
19	Poland			1	1	1			1								1	5
20	Portugal										2	1	2	2				7
21	Pakistan										1	2	2	1	1		1	8
22	Romania	1			1	3						1						6
23	Russia			2	1				3	2			1	1	3	6	2	21
24	Slovenia								1				1					2
25	Slovakia		2		1			1	1	2	4	1		3	2		2	19
26	Serbia														2	2	1	5
27	Spain															2		2
28	Sweden									1								1
29	Ukraine												2			1	1	4
30	USA															1	1	2
	Total	9	11	13	16	9	10	15	14	12	15	12	17	13	17	16	19	218

- France with the *Winter event* for French and FUSION-EP students in Cadarache, organized annually for several years when the TORE SUPRA and WEST tokamaks were out of operation. Happening in February, one week was devoted to the remote operation of COMPASS and with corresponding data analysis. The achieved results were presented in a closing workshop and evaluated by a jury.
- Serbia with the *Fuziona Obrazovna Mreze* (FOM) workshop, where students were taught in plenary lectures during 2 or 3 days and then spent two days analyzing GOLEM data obtained remotely under the supervision of scientists (some of them from IPP Prague). These students had to write a report on their 2 days analysis and the two best reports earned to participate in the forthcoming SUMTRAIC. This event which lasted 3 years, has, unfortunately, now ended due to lack of manpower, and was clearly inspired by SUMTRAIC/EMTRAIC.
- The CTU with a training course on the GOLEM tokamak, so called GOMTRAIC. During this one week event, students perform extensive experiments on GOLEM and acquire a

Table 6. Number of EMTRAIC students per year. Note that in 2020 EMTRAIC was organized remotely due to travelling restrictions.

2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
14	9	16	15	14	10	7	6	4	**95**

basic knowledge of tokamak operation and data processing. The peculiarity of this event is a hands-on experimentation with basic diagnostics that they install themselves on the tokamak.

3.3. EMTRAIC event

Thanks to our expertise in practical training (see the previous section about SUMTRAIC), IPP Prague was asked to organize a similar training for the second year master students enrolled in the Fusion-EP master. This training course is labelled as EMTRAIC, standing for Erasmus Mundus TRAIning Course, and takes place at the COMPASS tokamak at the beginning of December. Till now, 9 EMTRAICs were organized and more than 90 students have participated in the EMTRAIC event (see table 6). Note that the students (up to 15) usually come from all around the world and are enrolled in one of the eight partner universities of the European Master of Science in Nuclear Fusion and Engineering Physics. The interested reader is referred to [7] to learn more about the master organization.

The event is very similar to the SUMTRAIC one, i.e. the goal is to acquaint students with experimental physics on a tokamak and the structure and the duration of both events is similar. The few differences between the two lie in the fact that EMTRAIC is part of the students' curriculum (mandatory for all the second-year master students) and, therefore, is evaluated. Half of the grade is obtained by judging the students' presentations at the end of the workshop and half by grading a report-like article that the students have to write within two months after closing of the training course. Consequently, the level is usually higher than SUMTRAIC and the presentation ceremony is more strict, i.e. that the time for questions is used to judge on the level of the students. We attach in the supplementary data (available online at http://stacks.iop.org/EJP/42/045703/mmedia) an actual example of a student report to illustrate the work that students have to realize in the two-weeks of the event.

This event has proven to be useful for both parties, the Fusion-EP master and IPP Prague, the first one proposing to their students a training course on a real tokamak facility, the second one getting to meet and to educate students that have a high probability to continue working in the fusion area. In principle, one can imagine organizing such a type of events between national masters and fusion laboratories. It could increase the attractiveness of the master for students, as they usually tend to like practical training, and would surely create some strong bindings between the students and the laboratory. Illustrating this point, let us mention that it is not rare after EMTRAIC that the most skilful students continue working with their supervisors on their topics (see for instance [12–16] including Fusion-EP students that participated in EMTRAIC as coauthors). It helps not only for their education and training, but also to keep an eye on potential PhD candidates and talents.

Perspectives

With the forthcoming shutdown of COMPASS and the undergoing design of COMPASS-U, the tokamak department of IPP Prague will have to adapt its strategy in education, especially in the field of experimental physics. Luckily, designing a new machine like COMPASS-U requires the development of numerous systems, as plasma diagnostics, that are good opportunities to attract new students, especially from technical universities as CTU. In addition, a synergy can be found by combining the design of a new diagnostic, together with the exploitation of already acquired data from a similar system on COMPASS. In this way, the students have chances to also work on their physics skills and understand in depth the tool they are developing. In addition, theory or modelling can also be part of the PhD work and is often essential for designing a new diagnostic in a machine that does not exist yet. Last, joint PhD programmes allow to attract students that can participate in international collaborations and on running experiments or projects. The recent agreement between CTU and Ghent University in Belgium of running a bilateral joint doctoral programme and the good collaboration between CTU and IPP Prague enable that possibility. All these options are being considered by the IPP Prague.

The shutdown of COMPASS will also impact the way the two training schools SUMTRAIC and EMTRAIC are ran. It is clear from the past that the events can rely on the exploitation of already existing data and that it does not affect significantly their main aim. However, a special care was always taken to provide subjects on 'fresh' data, i.e. that were obtained recently, and from which the analysis was not performed yet and relevant to actual researches in the field. This was done both to keep the supervisors, which have to spend two weeks of their time on the subject, interested and to stimulate the excitement of the students to find something new and undiscovered. With COMPASS closing soon, finding suitable data to maintain that level of excitement for a group of 15 students will be challenging, even though there is about 20 TB of data on the IPP Prague database acquired for almost 20 years. Two solutions are envisaged at IPP Prague. First, reduce the attendance. Having less students joining the event would allow for a more strict selection, to reduce the load to the IPP Prague team already busy in the designing phase of a new machine and to lower the number of proposed subjects. Second, with the construction of COMPASS-U approaching, diagnostics should also become more mature. As a consequence, laboratory experiments will likely be performed by diagnosticians to properly setup and calibrate their diagnostics and would allow interesting topics for students. For instance, one could imagine a group of students working on the implementation of a visible camera, dealing with optics alignment, camera calibration with calibrated light sources, spatial and temporal resolution investigation, treatment of camera data.... These two solutions will help keeping alive SUMTRAIC and EMTRAIC during the transition period from COMPASS to COMPASS-U.

Another challenge that the IPP Prague has to face is the development of new numerical technologies and new approaches to fusion science, namely focusing more to technology than physics towards actual fusion power plants like DEMO. Clearly, thanks to the COMPASS-U project, the tokamak department will stay at the cutting edge of researches in the field of fusion. The constraints required to design such a machine (high vacuum vessel temperature and surface heat flux to mention only those two) have already shifted the research of the team more to the technological side, while keeping a physics strategy for when the device will be operational. It is therefore expected that students will be offered subjects following the recent development in fusion science and keep in touch with up-to-date research areas in the field.

Concerning numerical technologies, the tokamak department is lucky to rely on a young team. As a matter of fact, a team of PhD student held in 2019 a first internal two-days workshop, called code camp, aiming at developing new numerical tools for a general use of the department and discovery new numerical tools (machine learning, IA...). This event was planned to be held once or twice per year, but had to be cancelled in 2020 due to governmental restrictions on reunions. Another standing example showing the skills of the team in that area is the organization of EMTRAIC in December 2020 that was held completely online for the same reasons. The realization of this event was only possible because several tools, such as VPN, the jupyterhub already mentioned earlier [10], online meeting and chat rooms… were already in used at the tokamak department before 2020. It is believed by the authors that the IPP Prague is going in the right direction to keep up-to-date in that field too.

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