Preface

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When the decision was made to launch basic courses on the physics and technology of particle accelerators in the 1990s, this field was developing successfully at CERN, mainly for fundamental research in nuclear and particle physics. Not far from CERN, two other research laboratories were taking off and would soon gain an international reputation: 1) the Paul Scherrer Institute (PSI) in Villigen, Switzerland, with a large proton ring accelerator as its centrepiece; and 2) the European Synchrotron Radiation Facility (ESRF) in Grenoble, France. Taking advantage of the many technologies developed for these purposes, special applications related to health and industry were also being worked out. In the accelerator field, technicians and engineers learned their specialisation on the job and in specialised workshops organised by the laboratories, each lasting one or two weeks per year. Over time, and with the needs ahead, these learning opportunities began to appear insufficient; therefore, organising extensive courses, starting at the ground level, was considered to be necessary.

The 1990s saw the launch of the European student mobility programme ERASMUS, which encourages students to study abroad, promotes exchanges between universities, and introduced the European Credit Transfer System (ECTS). This was an exceptional opportunity to organise a course in this special area of research and development in the Geneva region, gathering students from different universities in Europe. The 1990s was also the era of the development of the Web and the extension of digital communication outside the research community. The environment was favourable—all that remained was to seize it and to reap its fruits. Building a common syllabus suiting the academic programmes of prestigious universities—each with different traditions—would have taken a long time without the strong will of a few scientists, the unfailing support of certain academic leaders and decision-makers, and the participation of open-minded accelerator scientists and engineers who were accustomed to working in an international environment.

The Joint Universities Accelerator School (JUAS) started in 1994 as “an experiment”. Today, its 30th birthday is being celebrated by the publication of these proceedings. This is a great achievement of European scientific and pedagogic collaboration, and a beautiful story. Throughout these years, scientists from all over Europe, eager to transfer their knowledge, have passed on the torch, improving the process at each step, delivering a comprehensive and up-to-date presentation of their specialties for newcomers in the field of particle accelerators. Most of them are not academic teachers but have professional responsibilities in research laboratories. We should all acknowledge their efforts to finalise their lecture notes and compile the many illustrative exercises with solutions! There is no doubt that future students and practitioners in the field will greatly benefit from these efforts. Despite the broad availability of digital documents, it is important to have key literature printed to avoid the risks of “electronic breakdown”. From the very beginning of the school, students requested written course notes, and studying using textbooks still seems to be valued.

The story becomes particularly beautiful as these proceedings are the result of the strong will—and hard work—of a former JUAS student (from the 1996 class). While pursuing a successful career as an accelerator physicist at CERN, he came back to JUAS for a parallel career, progressing from student to lecturer to Deputy Director and finally Director. I am very grateful to Elias Métral for having compiled these proceedings; they are a symbol of a great collective achievement. Others that must be included in these acknowledgments are former JUAS students (from the years 1994, 1997, and 1999)—by now

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lecturers who wrote some chapters of these proceedings—and senior scientists who have participated since the beginning of the school and remain members of the academic staff! It was a true delight to reconnect with their names after all these years. This renewed connection inspired me to accept the invitation to participate in this project, even as my scientific knowledge began to feel outdated. I extend my heartfelt gratitude to them and to everyone who helped to expand the school I initiated 30 years ago, especially in memory of those who are no longer with us.

Many new activities have been developed around the courses. In addition to the scientists who wrote the chapters of this book, others—from CERN and academic officials, members of school boards coming from universities and institutes across Europe, external tutors of practical works, visit guides, and administrative personnel—contributed behind the scenes to build what is now the full curriculum at JUAS. The students, for whom this book is written, also play an important role. Their questions and comments inspire the lecturers to reflect further on their own work, benefiting everyone involved. Their enthusiasm, combined with the active participation of the lecturers, has created an encouraging and stimulating environment.

Readers might study the full book, concentrate on special topics, or just have a glance. In any case, I wish you the same great feeling I got, realising the tremendous development in the field of particle accelerators over the last three decades and its expansion to become a dynamic interdisciplinary research area. I have been dumbfounded when faced with the level of complexity that some of the equipment has reached. I hope its future development finds a path in our new era of energy saving and preservation of the planet. Below, I will give only a short overview of the content of the full volume; the present state of basic knowledge on accelerators is to be found mostly in Parts I and II.

Part I, covering JUAS Course 1, is dedicated to the science of particle accelerators, i.e. the basic theoretical foundations. As in the subsequent part, many exercises are provided, along with their solutions, to give students a comprehensive understanding of each step. Two chapters outline the fundamentals of electromagnetism and special relativity that are required to understand how these machines work. A tutorial section and a few selected references complete this presentation. Two additional chapters provide an extensive overview of transverse and longitudinal beam dynamics, focusing on synchrotrons and storage rings. Two simulation codes are introduced from a practical point of view: MAD-X, which is widely used for transverse beam dynamics, and PyHEADTAIL, which is used for longitudinal dynamics. Then, different methods of injection and extraction of a beam in an accelerator are explained. As the machines are not perfect, one chapter addresses transverse linear imperfections and another one addresses non-linear effects, including methods for managing and partially correcting them. A chapter is devoted to synchrotron radiation, the source of more than 60 X-ray light sources in operation around the world. The interaction of X-rays with matter provides a wide range of applications for scientific research and industry, explaining the growing demand for new facilities. This is followed by a discussion of the advantages and drawbacks of linear accelerators. Their design and structure depend on the type of particles accelerated and the required parameters. Details of the technology are given. These machines have a large number of applications in healthcare and industry; in fundamental research, they are mainly used as injectors for synchrotrons and colliders. Collective effects perturb particle motion and play a crucial role in determining the ultimate performance of an accelerator. Cyclotrons, the most widely used hadron accelerators, are compact devices with a 100% duty cycle, making them well-suited for medical applications as well as nuclear physics research. Their underlying concepts are direct applications of the basics. This part concludes on a high note with the accelerator design workshop, which aims to apply the knowledge gained during the school to a realistic case study. This topic was introduced in 1997, and since then it has been very popular and is probably unique in its form. How it is taught has been revised and enriched over the years by successive lecturers.

Part II, covering JUAS Course 2, is the "heaviest" part: the technology and applications of particle accelerators. The first chapters deal with the core of the machines, the equipment that accelerates particle beams (RF systems) and those that bend or steer them (magnets). After reviewing the electromagnetism theory underlying the RF engineering of accelerators and the key aspects of this technology (cavities, power sources, etc.), a long chapter introduces basic RF concepts and principles relevant to the design of accelerator RF systems. The limitations of using copper technology to increase the particle energy led to the development of superconducting RF cavities. An overview of the state of the art of superconducting RF technology is given, and this underlines the importance of surface preparation and of diagnostics of RF superconductors. A similar approach applies to magnets: the foundational principles and tools required for the analytical design of a simple accelerator magnet are followed by those relevant to superconducting magnets. Here, superconductivity allows enormous savings in weight, volume, and energy consumption. Another chapter explores the advantages of using superconductors in accelerators, the conditions under which superconducting magnets and superconducting RF cavities are used, and the optimisations required for these materials. This is followed by a brief overview of cryogenics—applicable to the cooling of these superconducting devices—that "presents the basic processes, gives the correct orders of magnitude, and alerts the system designer to possible pitfalls". Another essential component of an accelerator is its vacuum system, as the circulating beam must avoid collisions with any molecules along its path to maintain its quality. Vacuum science and technology have been established and refined over a long period; however, since the advent of cryogenics in accelerators, vacuum conditions at cryogenic temperatures have been further studied, leading to the development of new technologies to achieve ultra-high vacuum levels. Beam instrumentation covers a "large and complex field". Knowing the beam parameters (beam current, profile, position, etc.) is essential for the operation and development of any accelerator. Particle sources are the equipment specifically designed to generate the particle beams; a chapter focuses on several types of sources according to the type of particles (electrons, positrons, or ions) and on the extraction of the beam from these sources. A chapter on survey and alignment explains how the components of an accelerator are positioned as close as possible to their theoretical position using geodetic metrology. Then comes a chapter on accelerator controls: "the control system is a central part of all accelerators. Its main task is to integrate the autonomous controllers distributed throughout the facility into a coherent infrastructure". A consideration of radiation safety provides insights into the importance of managing ionising radiation hazards, which are inevitable when working with accelerators. A detailed development of this topic addresses radiation shielding, safety systems, and monitors. Towards the end of this part of the volume, several specific accelerators are presented from an application standpoint: low-energy accelerators (the most numerous), with energies of less than 50 MeV, have now achieved compact, reliable, and efficient designs and are widely used in medicine and industry; high-power proton linacs are considered as drivers for energy saving, material science, etc.; manufactured cyclotrons that can produce protons/ions of a few hundred MeV for medical treatments; and a particular compact recirculating electron accelerator for industrial applications. The chapter on the physics of particle therapy explains the choice of proton/ion beams to treat cancer and the role of the gantry in transporting and positioning the beam for the patient. This part concludes with a chapter on the life-cycle and operation of particle accelerators.

Part III features the seminars given to illustrate the courses. What purposes do the accelerators serve? How did the technology develop? What are the links between the different fields in which accelerators are used? Insights into practical applications improve the integration of the courses. The ongoing demand from fundamental research and societal applications is now evolving within the framework of sustainability, leading to the introduction of new technologies that shift from "incremental innovation" to "disruptive innovation". The evolution of the CERN accelerator complex over 70 years is a good example of the remarkable development of the discipline. In the 16 chapters, many colliders are reviewed; these machines allow high energies to be reached, seeking to produce new particles. Some of these are already in operation, while others are under construction or still at the research stage. Other recent facilities include X-ray free-electron lasers (FELs), energy-recovery linacs (ERLs), and accelerator-driven systems (ADSs), which are being considered for the transmutation of long-lived nuclear waste. Machine learning, as a mathematical tool, is investigated for its potential to improve accelerator operation. One chapter illustrates the design of beamlines derived from the main CERN accelerators (PSB, PS, and SPS) for fixed-target experiments. Radiation oncology (biology, physics, and clinical applications) is introduced by a hospital doctor, focusing on historical developments and future perspectives; vast improvements in curability and reduced toxicity have already been obtained.

Part IV is an **appendix** to these proceedings, dedicated to the origin and history of this unique school. It shows how its present status results from successive improvements in the syllabus, pedagogy, and organisation due to the ongoing efforts of the JUAS Directors and boards. They follow the ongoing developments in the field and strive to meet the requirements of all those involved, including partner universities and institutions, whose numbers have increased over the years. While the main structure has remained unchanged from the beginning—consisting of two five-week sessions dedicated to the science and technology of particle accelerators within an academic framework—much more time is now devoted to direct interaction between students and scientists. The administrative structure is presented alongside its main support, the European Scientific Institute (ESI). Following this, some enlightening statistics regarding the students, lecturers, contributors, and partner universities and institutions are provided. The progression of female participation over the years still seems to be slow, despite the presence of some prominent role models in the discipline. It takes time for women to find their rightful place and become visible. The 2024 classes of JUAS, with almost equal representation of female and male students, offer some hope. The seven successive Directors reflect on their respective periods and offer their personal viewpoints. Group photographs taken over the years make a veiled reference to the passage of time, while many other images perfectly illustrate the permanent academic ambiance, which is both cheerful and serious.

Skimming through the full volume has been a tonic experience. I would like to thank the editorial board for inviting me to write this preface, which I have done in an old-fashioned way, without using AI! “AU REVOIR!” said the penguins on the card signed by the first JUAS class in 1994. Today, I wish JUAS a long life!


AU
REVOIR!