Preface

The realm of particle physics is vast: multidisciplinary knowledge across several domains of physics and mathematics is required to understand the reactions that occur when particles collide and to master the functioning of the experiments built to study these reactions: classical and quantum mechanics, special relativity, electrodynamics, thermodynamics, chemistry, atomic and nuclear physics, quantum field theory, electronics, analysis, geometry, group theory, probability, informatics, among the others. Large-scale particle experiments, like those hosted in the main laboratories around the world, are perhaps the best example of how multidisciplinary this field can become: the successful operation of these complex structures relies on the synergetic work of hundreds of scientists and engineers; it is only the combination of their individual expertise that makes it possible to cover all the needs.

Thanks to the maturity of this field (more than one hundred years old!), a huge collection of textbooks, topical schools, academic classes, and scientific literature is available, where both the theoretical and experimental foundations of particle physics can be elucidated to the desired level of detail. Yet, as for all the other domains of physics, particle physics should be more about solving problems rather than knowing concepts! The path towards a solid understanding of this discipline passes through the capability of solving exercises. This book collects a sample of about 240 solved problems about particle physics in general. About half of the exercises are drawn from the public exams that have been proposed by the Italian National Institute for Nuclear research (INFN) to select its scientific staff over the last decade. Additional material inspired by my personal experience as an undergraduate student at Scuola Normale Superiore di Pisa, researcher in the CMS experiment, and teaching assistant at ETH Zürich complements the selection. Throughout this book, the main emphasis is put on experimental problems, although some more theoretical ones are also included. Thus, this book is mostly addressed to experimentalists.

The proposed exercises span several subjects in particle physics, although I must acknowledge that it has not been possible to be truly exhaustive. Several topics have been unfortunately, yet necessarily, discarded or only marginally mentioned.

In particular, cosmology, dark matter, beyond-standard model theories will not be much discussed here. Also, a personal cultural bias towards an LHC-centric vision of the field may have driven the focus towards the high-energy frontier at the expenses of other equally lively sectors of research, like neutrino physics, rare decays, hadron spectroscopy, B physics. Much attention is devoted to the operational principles of particle detectors, from the more classical ones to the more recent technologies. Particle detectors cannot be understood without first mastering the basics of the interaction between particles and matter, which therefore represents another topic of foremost interest. Given that particle detectors typically provide electric outputs, which need to be processed, stored, and cleaned from the noise, electronics, informatics, and data analysis enter naturally into the game, and a basic knowledge of both subjects is therefore required. Furthermore, an experiment in particle physics usually starts by scattering particles: acceleration of particles in stable and repeatable beams is therefore another important topic. Finally, a proper scientific maturity demands also an overall picture of the field: what is known, what is still unknown but important to study, what are the technologies at hand, and what the future lines of research. Several exercises go along this direction by discussing the state of the art on the field, including ongoing or planned measurements and new experimental techniques.

The exercises are grouped by subject into five chapters, where the main topic of discussion is first introduced in an academic fashion. Within each chapter, the exercises are organised as much as possible according to a logical order, so that each exercise can be propaedeutic to those that follow. Some of the exercises are used as prototypes for a class of problems. In this case, the relevant concepts and the general-purpose formulas are derived once and recalled afterwards by pointing to the master exercise. Other exercises are instead chosen to introduce a particular topic, which is then explained in some more detail by dedicated mini-lectures. References to the scientific literature and topical textbooks are then provided to help the reader go into the various subjects in greater detail. Consistency of notation throughout the text is pursued to reduce at a minimum the confusion introduced by the abundance of acronyms and conventional symbols peculiar to this field. Some exercises require a few lines of calculations, others one or more pages. Whenever possible, one should always try to derive the symbolic solution analytically and carry out the numerical computation without the help of pocket calculators, as to train one's capability to handle simple calculations using approximations or order-of-magnitude estimates. Indeed, experience teaches that there exist a few constants and formulas that are really worth keeping in mind! In other situations, one should better rely on computers rather than try the analytical approach. In the latter case, examples of simple computer routines written in open-source programming languages are also proposed.

Per aspera ad astra: solving problems is the most difficult and painful task for students, but also one that unveils the true degree of comprehension of the subject. We hope that this book can serve as supporting material to back up existing and more complete textbooks on experimental and theoretical particle physics. At the same time, it should provide a test bench for undergraduate students and young

researchers to validate their level of preparation and hopefully stimulate their curiosity on the field.

I am much indebted to INFN for allowing me to profit from a large number of the exercises contained in this book. The richness and variety of topics covered in this immense reservoir of knowledge have been fundamental to shape this work. I also want to heartily thank the Institute for Particle Physics of ETH Zürich for granting me the time to work on this book and for the fantastic teaching experience I enjoyed amid its brilliant and lively students.

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September 2017

http://www.springer.com/978-3-319-70493-7

Selected Exercises in Particle and Nuclear Physics

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2018, XIV, 364 p. 56 illus., 40 illus. in color., Hardcover
ISBN: 978-3-319-70493-7