

Preface

Soon I knew the craft of experimental physics... the sublime quality of patience – patience in accumulating data, patience with recalcitrant equipment. . .

Abdus Salam

I have had the privilege of being a wanderer in the diverse world of physics. That privilege vested in me an appreciation for all of physics, filling me with wonder. But when I became an accelerator physicist in 1990, I experienced the true joy and fulfillment that only something truly sublime could bring. I saw how physics principles, ranging in complexity from simple, elegant laws, to hard to understand complex notions, had to come together in defining the mission of large physics facilities. I saw the true nature of spectacular experiments, facilities, and cutting-edge technologies that must be developed and built, to go on a quest for the ultimate discoveries in physics. The enormity of the scientific, engineering, and management endeavor fascinated me, while the politics vexed me. I felt the excitement of a child who gets on a ride in an amusement park for the first time. The Large Hadron Collider came on line, sparking the imagination of physicists and the general public alike. This increased my pulse rate. I felt I had to tell someone about what accelerators–colliders–detectors are, and how they came about. Hence the book.

I also feel that the public should weigh in strongly on the decisions to pursue the increasingly complex and expensive physics experiments. This is only possible if they understand the concepts and implications, to the depth that is required in order that no one can manipulate their opinions. So while this book has a fair amount of mathematical descriptions and what might be, to lay people, difficult concepts, it is still possible for a lay reader to skip such sections and appreciate the motivations, principles, and efforts required to build particle accelerators and detectors. In this context, readers are urged to take note of the large number of occasions when a scientific invention intended only for a specific experiment resulted in a major technological application. Examples range from the Cathode Ray Tube to X-rays to nuclear power to the Internet.

Another motivation for writing this book is to provide reading material for undergraduate science and engineering students. A good familiarity with this

branch of physics that connects to the greatest aspirations of physicists would increase their love for science and their commitment to pursue it, either in their career or as a hobby. Therefore, this book has been written at a somewhat higher level than popular physics and includes several detailed derivations. In all cases, there has been an attempt to provide as complete a description as possible on a given topic, while limiting it to undergraduate level math. Overall, the book is written to provide a comprehensive understanding of the chain of developments. Details and some math are added where necessary, to clarify the concepts. With this approach, it is hoped that undergraduate students would find it a satisfying read while enriching their knowledge in the field of physics. I hope this book will also provide a context to their course work, and firm up their learning.

The evolution of accelerators has been rapid, and makes for a fascinating story. Over the last several decades, the development of physics itself has been closely linked to this evolution. Therefore, the chapters describe the developments in accelerators and detectors through linkages to fundamental physics goals of the time. The fascinating history of very humble beginnings with terrestrial radioactive sources of particles to the modern day powerful colliders, is told through narratives that include human interest stories as well as physics content. In addition to photographs and illustrations, cartoon illustrations are included to provide analogies and to lighten up these heavy descriptions. All along, attempt has been made to convey the excitement of the discoveries, and the admiration and wonder that the author feels when thinking about the science and the scientists. When experimental facilities grew very large, and governments became the only possible sources of funding, the history of high-energy particle experiments, like most branches of big science, became permeated with politics, for good or bad. The narration includes cases where politics was instrumental in shaping the outcome.

The first three chapters provide the background and motivation that led to the discovery of the first particle accelerators. The first two chapters trace the development of the notion of atoms, the discovery of electromagnetism, and the first discovery of a fundamental particle – the electron. These chapters also show the methodology of research that set the trend for future generations of researchers. Chapter 3 shows that man-made instruments such as the Cathode Ray Tube themselves spurred the investigation of new kinds of radiation – the alpha, beta, and gamma rays. The discovery of these rays led curious physicists to inquire into the structure of the atom itself, gaining a first glimpse into Nuclear Physics. The abiding discovery of cosmic rays and their measurement then rounded up the natural sources of particles that provided almost all of the physics clues of the early 1900s.

Chapter 4 then narrates the physics and history of the invention of the first accelerators, along with associated discoveries. The use of magnetic fields in building compact accelerators also led to new accelerator physics principles, sparking research into “betatron oscillations”. Chapters 5–7 continue the narration, describing circular accelerators and the major discoveries that were made using these. The chapters describe how these machines grew from a size that would fit in the palm of a hand while providing tens of kilo electron volts of energy to “Rings of

Earth”, which would enclose vast tracts of land and produce particle energies of trillions of electron volts. The physics of particle acceleration using radiofrequency fields and the behavior of particles in such a matrix of accelerating geometry is presented concisely. Simultaneously, the story of the centers of particle accelerators and high-energy physics research, such as the Brookhaven Laboratory and the CERN, is told. Chapter 8 describes the superconducting circular accelerators and the cutting-edge technologies that make them possible. Chapter 9 continues the story of the fascinating evolution of linear accelerators, which was interrupted by the development of circular accelerators, but set back on course by new physics and technology. Chapter 10 is relatively more difficult, dealing with the physics that is on the minds of researchers of today. Here is a glimpse into the rich and complex physics that encompasses present understanding, and the questions that remain unanswered. It departs from the narration of the previous chapters in that little mention is made of particle accelerators. Instead, the physics discoveries, many of which were theoretical, are presented as a foreground to present quests in the frontiers of physics. Following this physics, the engineering, technology, and management backgrounds of particle colliders and detectors are given in Chaps. 11 and 12. Finally, Chap. 13 describes the 7 TeV on 7 TeV Large Hadron Collider, the pride of the physics nation. Included in this chapter are the promise of this fantastic experimental facility and explanations on some of the myths that surround it. In this way, the book is hopefully a journey through the history of particle physics and accelerators, leading to the present. Through this journey, it is hoped that readers would acquire adequate familiarity so that they would recognize the subcomponents of accelerators and detectors if they were to visit a facility.

The writing of this book has itself been a journey and a personal quest for me. Hence I would like to acknowledge with gratitude those who helped me along the way. Dr. Ramon Khanna has been a critical editor who, along with the editorial team, guided the content and reviewed the material critically. I wish to thank my wife Suhasini Jayakumar for her critique and help with the narration and editing. I also acknowledge, with immense gratitude, all the people and institutions that gave permission to use their illustrations and photographs and gave helpful comments.

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Energy Physics

Charming the Cosmic Snake

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