Gauge Theories

of the Strong and Electroweak Interaction

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Preface

The gauge theories for the strong and electroweak interaction have become the Standard Model of particle physics. They realize in a consistent way the requirements of quantum theory, special relativity, and symmetry principles. For the first time, we have a consistent theory of the fundamental interactions that allows for precision calculations for many experiments. The Standard Model has, up to now, successfully passed all experimental tests. This success establishes the importance of gauge theories, despite the fact that gravity is not included and that the Standard Model is most likely an effective theory resulting from the low-energy limit of a more fundamental theory.

The aim of this book is to present the basic ideas and concepts, the technical tools, and the predictions of the gauge theories for the fundamental constituents of matter and their interactions: Quantum Chromodynamics for the strong interaction and the Electroweak Standard Model for the unified electromagnetic and weak interaction.

The first edition of this book, P. Becher, M. Böhm and H. Joos, *Eichtheorien der starken und elektroschwachen Wechselwirkung*, appeared in German in 1981. At that time, gauge theories were not yet really supported by experiment. The W and Z bosons were not discovered, the existence of the gluon was not confirmed, and the top-quark had not been found. Presently, after a lot of theoretical and experimental work, gauge theories are much better understood, many precision calculations exist, and a huge amount of experimental data is available. All this has put the gauge theories on a firm ground and required a thorough revision of the original book. This third edition is almost completely rewritten and largely extended. We tried to cover the most important developments and to guide the reader to the modern applications of gauge theories in elementary particle physics.

As before, this book is written for students who have passed the standard course in theoretical physics and an introductory course in particle physics. The book is also addressed to experimental and theoretical physicists who want to become familiar with the established treatment of the fundamental

interactions. We tried to cover a large part of the applications of gauge theories, to present the material in a self-contained form, and to show in detailed calculations, as far as possible, how the results are obtained. In order to help the reader to get along with this huge amount of material we supply a detailed index and a large list of references. Evidently, the list of references cannot be exhaustive. We tried to focus on original papers, review papers, and articles that, in our opinion, should help the reader in understanding the subjects.

In the first part of the book, we review the basic concepts of the phenomenology of particle physics and relativistic quantum field theory. Then, we treat the quantum theory of gauge fields in detail. We work out the invariant perturbation theory including Feynman-diagram techniques and renormalization, which is the basis for many precision calculations. The topological properties of gauge theories are important for their non-perturbative evaluation. We discuss, in particular, instanton solutions of gauge theories and gauge theories on the lattice. This knowledge of the structure of gauge theories and of the methods for their evaluation is then applied to Quantum Chromodynamics and the Electroweak Standard Model. We conclude with short a survey of grand unified theories and supersymmetry.

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Corrections to this book

A list of misprints and corrections to this book is posted on the World-Wide Web at the URL `http://www.hep.psi.ch/denner/GTupdates.html`, or can be obtained by writing to the authors. We would be grateful, if you would report addtional errors in the book to Ansgar.Denner@psi.ch.