This book provides an easily accessible introduction to quantum field theory via Feynman rules and calculations in particle physics. The aim is to make clear what the physical foundations of present day field theory are, to clarify the physical content of Feynman rules, and to outline their domain of applicability. The book begins with a brief review of some aspects of Einstein's theory of relativity that are of particular importance for field theory, before going on to consider the relativistic quantum mechanics of free particles, interacting fields, and particles with spin. The techniques learnt in these chapters are then demonstrated in examples that might be encountered in real accelerator physics. Further chapters contain discussions on renormalization, massive and massless vector fields and unitarity. A final chapter presents concluding arguments concerning quantum electrodynamics. The book includes valuable appendices that review some essential mathematics, including complex spaces, matrices, the CBH equation, traces and dimensional regularization. An appendix containing a comprehensive summary of the rules and conventions used is followed by an appendix specifying the full Langranian of the Standard Model and the corresponding Feynman rules. To make the book useful for a wide audience a final appendix provides a discussion on the metric used, and an easy-to-use dictionary connecting equations written with a different metric. Written as a textbook, many diagrams and examples are included.

This book will be used by beginning graduate students taking courses in particle physics or quantum field theory, as well as by researchers as a source and reference book on Feynman diagrams and rules.

CAMBRIDGE LECTURE NOTES IN PHYSICS 4

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Diagrammatica
The Path to Feynman Rules

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Diagrammatica

The Path to Feynman Rules

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Introduction

In recent years particle theory has been very successful. The theory agrees with the data wherever it could be tested, and while the theory has its weak spots, this numerical agreement is a solid fact. Physics is a quantitative science, and such agreement defines its validity.

It is a fact that the theory, or rather the successful part, is perturbation theory. Up to this day the methods for dealing with non-perturbative situations are less than perfect. No one, for example, can claim to understand fully the structure of the proton or the pion in terms of quarks. The masses and other properties of these particles have not really been understood in any detail. It must be added that there exists, strictly speaking, no sound starting point for dealing with non-perturbative situations.

Perturbation theory means Feynman diagrams. It appears therefore that anyone working in elementary particle physics, experimentalist or theorist, needs to know about these objects. Here there is a most curious situation: the resulting machinery is far better than the originating theory. There are formalisms that in the end produce the Feynman rules starting from the basic ideas of quantum mechanics. However, these formalisms have flaws and defects, and no derivation exists that can be called satisfactory. The more or less standard formalism, the operator formalism, uses objects that can be proven not to exist. The way that Feynman originally found his diagrams, by using path integrals, can hardly be called satisfactory either: on what argument rests the assumption that a path integral describes nature? What is the physical idea behind that formalism? Path integrals are objects very popular among mathematically oriented theorists, but just try to sell them to an experimentalist. However, to be more positive, given that one believes Feynman diagrams, path integrals may be considered a very valuable tool to understand properties of these diagrams. They are justified by the result, not by their definition. They are mathematical tools.

Well, things are as they are. In this book the object is to derive Feynman rules, but there is no good way to do that. The physicist may take a pragmatic attitude: as long as it works, so what. Indeed, that is a valid attitude. But that is really not enough. Feynman rules have a true physics content, and the physicist must understand that. He/she must know how Lorentz invariance, conservation of probability, renormalizability reflect themselves in the Feynman rules. In other words, even if there is no rigorous foundation for these rules, the physical principles at stake must be understood.

This then is the aim: to make it clear which principles are behind the rules, and to define clearly the calculational details. This requires some kind of derivation. The method used is basically the canonical formalism, but anything that is not strictly necessary has been cut out. No one should have an excuse not understanding this book. Knowing about ordinary non-relativistic quantum mechanics and classical relativity one should be able to understand the reasoning.

This book is somewhat unusual in that I have tried very hard to avoid numbering the equations and the figures. This has forced me to keep all derivations and arguments closed in themselves, and the reader needs not to have his fingers at eleven places to follow an argument.

I am indebted to my friends and colleagues R. Akhoury, F. Erné, P. Federbush, P. Van Nieuwenhuizen and F.J. Yndurain. They have read the manuscript critically and suggested many improvements.

The help of M. Jezabek in unraveling the complications of metric usage is gratefully acknowledged. I have some hope that this matter can now finally be put to rest, by providing a very simple translation dictionary.

Ann Arbor, December 1993