Preface

Quantum Chromodynamics (QCD) continues to be an active field of research, which one can see from the number of publications in the field, as well as from the number of presentations at different QCD dedicated conferences, such as the regular QCD-Montpellier Conference Series. This continuous activity is due to the relative difficulty in tackling its non-perturbative aspects, although its asymptotic freedom property has facilated perturbative calculations of different hard and jet processes. Therefore, we think it is still useful to write a book on QCD in which, besides the usual pedagogical introduction to the field, some reviews of its modern developments, which have not yet been 'compiled' into a book, will be presented. Elementary introductions at the level of pre-Ph.D. in different specialized topics of QCD will be discussed, which may be useful for a future deeper research and for a guide in a given subject.

We start the book with a general elementary introduction to strong interactions, parton and quark models, . . . , and present the basic tools for understanding QCD as a gauge field theory (renormalization, operator product expansion, . . .). After, we present the usual hard processes (deep inelastic scattering, jets, . . .) calculable in perturbative QCD, and discuss the resummation (renormalons, . . .) of the perturbative series. Later, we discuss the different modern non-perturbative aspects of QCD (lattice, effective theories, . . .). Among these different methods, we discuss extensively, the method and the phenomenology of the QCD spectral sum rules (QSSR) method introduced in 1979 by Shifman–Vainshtein and Zakharov (hereafter referred to as SVZ) [1]. Indeed, we have been impressed by its ability to explain low-energy phenomena such as the hadron masses, couplings and decays in terms of the first few fundamental parameters of QCD (QCD coupling, quark masses, quark and gluon condensates), and vice versa, we have been fascinated by the success of the method to extract the QCD universal parameters from experiments. In this respect, some parts of this book have been updated, improved, extended and included a latex version of the former review [2]:

Techniques of dimensional regularization and renormalization for the two-point functions of QCD and QED, S.N., *Phys. Rep.* 84 (1982) 263

and of the book [3]:

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QCD Spectral Sum Rules Lecture notes in Physics, Vol. 26 (1989) World Scientific Publ. Co. Singapore.

However, the discussions in this book cannot replace the previous ones (hereafter referred to as QSSR1), as some detailed analyses carried out in the older review and book are not reported and repeated here. In this present book, we limit ourselves to review the most recent results and new developments in the field, without going into some technical details, and, in this sense, this book is a useful supplement to the former. Various misprints in QSSR1 have also been corrected.

As we have already mentioned, and as in the previous review and book, we have written this book for a large audience, not necessarily working in the field (elementary introduction to QCD, . . .). However, experts will also appreciate this book, as they will find the most relevant and the latest results obtained so far with the QSSR method. They can also find compilations of non-trivial QCD expressions of the two-point correlators obtained within the Operator Product Expansion (OPE), and technical points relevant to the method itself (mixing of operators under renormalizations, validity of the SVZ expansion . . .). Experimentalists will find in this book a 'quick review' of most of important results obtained from QSSR.

However, because of the large *horizontal* spectrum of the QSSR applications in different branches of low-energy physics, including nuclear matters, which we (unfortunately) cannot cover in this book, we shall limit ourselves to the well-controlled and simplest applications of the methods, namely the light and heavy quark systems and to a lesser extent the gluonia and hybrid meson channels. At present, these examples are quite well understood and will, therefore, serve as *prototype* applications of QSSR in high-energy physics and quantum field theory. Some other applications of QSSR, such as in the QCD string tension, in the composite models of electroweak interactions (QHD sum rules) and in supersymmetric QCD, were already discussed in QSSR1 and will not be discussed in detail here, since there has been no noticeable recent developments in these fields of applications, since the publication of QSSR1. We shall not discuss the uses of QSSR for nuclear matters, either, since the complexity of these phenomena still needs to be better understood. However, the enthusiasm of nuclear physicists for using this method in the baryonic sector might be restrained, owing to the delicateness of the corresponding analysis, which in my opinion has not yet been improved since the original work, in which the obstacle is due to the optimal choice of the nucleon operators. At the present stage, one can only consider the analysis done in the baryon sector to be very qualitative.

Following (actively) the developments of QCD through those of QSSR since its birth in 1979, my feeling à la Feynman (Omni magazine 1979), advocated in QSSR1 about this field remains unchanged (as already quoted in QSSR1):

. . . A few years ago, I was very skeptical . . . I was expecting mist and now it looks like ridges and valleys after all . . . ,

while the *great* success of QSSR in the understanding of the complexity of low-energy non-perturbative phenomena and hadron physics, is well illustrated by the Malagasy saying:

'Vary iray no nafafy ka vary zato no miakatra!.'

which means: with one grain of rice sowed, one can gather by the thousand!, or in other words, the method has started quite modestly and, with time, it has become more and more underground. Indeed, at present, QSSR (*used correctly*) is one of the most powerful methods for understanding (*analytically*) the low-energy dynamics of hadrons using the few fundamental parameters (coupling, masses and condensates) coming from QCD first principles.