Preface

“What are the elementary building blocks of the world and ourselves?” is a question occurring in the human mind from ancient times. Aristotle, one of the great Greek philosophers, believed that the world is made of Earth, Air, Fire, and Water. In ancient China, people thought that everything arises as a composition of the five elements of Earth, Wood, Fire, Metal, and Water. However, most of these thoughts are in the sense of philosophy. It became a scientific problem since the proposal and discovery of *molecules* and *atoms*. As the technique of probing the structure of matter improves, atoms are found to be composed of more fundamental elements, i.e., the nucleus and electrons. Such a decomposition line extends continuously, and nowadays the most fundamental elements are electrons and quarks, the latter of which make up the baryons and mesons. The typical size of electrons and quarks is less than 10^{-15} meter. It is such a small size that one cannot imagine it ordinarily. These elements are called *particles* academically.

Another important discovery in probing the structure of matter is that the rules to govern the particles are very different from those in the macro-world. They are so weird that even scientists cannot understand them intuitively. For example, the state of a particle cannot be measured accurately in a fixed space. They can move with unspecified momentum. In other words, the momentum is not fixed before a measurement. Furthermore, particles possess a special property, called *spin*, which seems related to the rotation of something in particles. But in fact spin is not so simple and just a unique property in the micro-world. Especially, the value of a particle’s spin is fixed all the time and takes only integers or half integers. The known particles have only spins of 0, 1/2 or 1. The spin-1/2 particles include electrons and quarks while the spin-1 particles are mediators of the forces among the spin-1/2 particles, such as photons. The only spin-0 particle was newly discovered in 2012, which plays a crucial role in explaining the masses of spin-1 and spin-1/2 particles.

It is a fantastic work to establish such a framework, called the standard model of particle physics, about the construction of the world. People are confident to describe and explain almost every phenomenological event with this framework in hand. However, it is not the final and perfect theory about the world, though the framework has been indeed tested by a number of experiments. There are some phenomena that cannot be explained in the framework. Pursuing a more complete theory is still an existing aim of scientists.

In order to look into the inner structure of tiny particles, the only way is to let other particles collide with them to break them apart. The more energy there is in the collision, the finer the structure people can see. Since protons are heavier than electrons, it is easier to accelerate them with high energy. Quarks are the building blocks of protons, and therefore a precise understanding of the interaction involving quarks is the basis for discovery of any new physics. Quantum Chromodynamics (QCD) is the theory to describe the interaction involving quarks. However, it is so complicated that exact solutions cannot be obtained. The prediction made by QCD can only become more and more precise after including more and more corrections. As a consequence, it is important to consider QCD high-order corrections in searching for new physics.

This is the motivation for my Ph.D. thesis. Most of the contents in this thesis have been published in the form of academic papers. However, I provide in this book more updated introductions to the backgrounds and recent developments in the relevant fields, and show more useful details in my research that are not appropriate for publication in scientific journals. Thus, I believe that graduate students can benefit from this book.

The main contents of this thesis are arranged as follows. We first introduce the present knowledge about the micro-world, the standard model of particle physics in Chap. 1. In Chap. 2, the bases of Quantum Chromodynamics, including the history, quantumlization, and renormalization, are reviewed. Then in Chap. 3 the perturbative QCD calculation of the scattering processes at hadron colliders is described, especially the factorization, infrared safety, QCD higher-order effects, and resummation methods. In Chap. 4, the potential of the LHC to discover the signal of dark matter associated production with a photon in an effective theory is studied. In Chap. 5, the factorization and resummation of the prediction for the top quark transverse momentum distribution at large p_T at both the Tevatron and the LHC are discussed with soft-collinear effective theory. In Chap. 6, the potential of the early LHC to discover the signal of monotops, which can be decay products of some resonances in models such as R-parity violating supersymmetry (SUSY) or $SU(5)$ grand unification model, is investigated. Chapter 7 is a summary of this thesis and also an outlook is presented. Some calculation details and parameters used in the calculation are given in the appendices.

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