Chapter 0

Introduction

As we start this study of *Particles and Symmetries* it is appropriate to begin with a description of the overall goals of the course. As the title implies, our intent is to provide an introduction to an area of physics that has seen dramatic progress in the last 50 years — elementary particle physics. A central tool underlying this progress has been the exploitation of symmetries, the other subject in the title, reflected in the interactions of particles. The understanding which has emerged is encoded in the so-called Standard Model of particle physics, which identifies the fundamental particles and interactions among these particles relevant for describing nearly all of the physical universe. When we include collective behavior (quarks bounds in nuclei, electrons bound in atoms, atoms bound in solid matter) plus classical gravity, we have a nearly complete explanation for the physics observed on the largest distance scales, *e.g.*, the evolution of the universe from very early times, down to the shortest distances probed at particle accelerators. To have full quantitative command of this fundamental understanding requires some tools not at our disposal, namely quantum field theory. However, using only special relativity, basic quantum mechanics, and symmetries, one can understand a surprisingly large portion of particle physics in an accessible and relatively quantitative fashion.

From a pedagogical perspective, this endeavor will provide an opportunity to discuss special relativity in detail, and practice using it to describe the kinematics of particle collisions at high energy. Key concepts will include 4-dimensional momentum conservation (which is itself associated with the invariance of physics under translations in space and time), and the universal speed limit set by the speed of light. We will work to develop practical facility with 4-vector notation and the transformations (boosts) that relate quantities in different inertial reference frames. From quantum mechanics we will make heavy use of the uncertainty principle, and the important role played by simultaneous eigenstates of mutually commuting operators. You should have seen some of this structure in the context of quantized angular momentum. We will use symmetries (and a bit of the underlying mathematics of group theory) to tie this all together. This will include the use of approximate symmetries, where there is not exact invariance under some transformation, but rather the transformation induces "small' perturbations. This will allow us to separate big effects from small effects, or more formally organize perturbative expansions in these small effects (another essential tool for your physics toolbox). All during the course, you will also be honing your skill for making order-of-magnitude estimates, *i.e.*, being able to quickly estimate a rough value for some physical quantity even when you do not know all the details.

Do not be concerned if not all of these concepts are clear on first reading — clarity should improve as the course progresses.