Available online at www.sciencedirect.com

ScienceDirect

Physics Procedia 51 (2014) 25 – 30

Physics Procedia

ESS Science Symposium on Neutron Particle Physics at Long Pulse Spallation Sources, NPPatLPS 2013

Low-energy precision physics and the high-energy frontier

Adrian Signer

LTP, Paul Scherrer Institute, 5232 Villigen, Switzerland,
ITP University of Zurich, Winterthurerstrasse 190, 8057 Zurich, Switzerland

Abstract

Despite numerous searches for physics beyond the Standard Model at high-energy colliders and low-energy experiments, no compelling evidence has been found. If this continues to be the case after the LHC has started operating at a centre-of-mass energy of 13 TeV or higher, low-energy precision physics will become even more important in constraining or finding physics beyond the Standard Model. In this article a very basic overview is given over the interplay between high-energy and low-energy observables in uncovering the nature of new physics. To this end an effective theory approach is discussed and examples for its application are given.

Keywords: Effective theory; LHC; low-energy precision experiments; beyond the Standard Model.

1. Introduction

The Standard Model (SM) is an extremely successful theory. It has passed a very large number of ever more precise experimental tests. Despite all effort, no solid evidence for physics beyond the Standard Model (BSM) at any collider experiment has been found. The recent discovery at CERN of a particle consistent with the long-sought Higgs boson is yet another chapter in this story. Indeed, the couplings of this particle are in very good agreement with what was predicted for the SM Higgs and its mass is also in perfect agreement with what was expected from indirect constraints from precision measurements.

In addition to searches at high-energy colliders, very stringent tests of the SM are being done using low-energy observables. Once more, a large number of measurements show excellent agreement with theoretical predictions within the SM. There are a few cases such as the anomalous magnetic moment of the muon, Bennet et al. in [1], or the proton radius, Antognini et al. in [2], where there is a tension between the prediction and the measurement. However, it is more likely than not that the origin of these small discrepancies is not due to BSM physics.

doi:10.1016/j.phpro.2013.12.007

This leaves us with a peculiar situation in particle physics. On the one hand we have this immensely successful theory. On the other hand we know that the SM cannot provide us with answers to a number of crucial questions. It does neither explain dark matter nor the dominance of matter over antimatter in the universe. It also fails to provide a solution to the so-called strong CP problem and makes no attempt to describe dark energy or gravity to name just some of the shortcomings.

There has been a huge effort in trying to find an extension to the SM that provides answers to at least some of the questions that are unanswered by the SM. This has to be achieved without disturbing the spectacular agreement of theory with collider experiments. The decisive question is at what scale Λ_{UV} does new physics show up. There are good theory arguments to believe that this scale is at around 100 GeV to 1 TeV. However, the lack of any sign of BSM physics at the Large Hadron Collider (LHC) has put these arguments under pressure. Of course, there is another big step ahead with the increase of the centre-of-mass energy at the LHC from 8 TeV to 13 or 14 TeV. If the arguments hinting at $\Lambda_{UV} \sim 1$ TeV are correct, the LHC should be capable of producing at least some of the new particles.

Of course, the high-energy frontier is not the only option to look for BSM physics. Rather than manifesting itself through new particles as external states, BSM can modify processes with only SM external particles through virtual effects. In fact, some of the indirect constraints mentioned above related to the Higgs boson are an interplay of such virtual effects with SM particles in the loop. BSM particles can act in a similar way and modify couplings and cross sections of SM particles. The size of these deviations from the SM depends crucially on the mass scale of the BSM particles and their coupling to SM particles.

Thus, broadly speaking there are two possible scenarios for particle physics in the years ahead. Either the LHC discovers BSM physics and gives us reasonably concrete information about its nature, or the SM continues to pass all tests and constraints on BSM models become even more stringent. As we will discuss in Section 2, in the former case, theory is in very good shape to deal with the challenges ahead. In the latter case, however, it is very likely that we will need to combine information from all possible sources and low-energy observables will play an even more important role. In Section 3 we will describe an effective-theory approach that allows for a general parameterization of BSM physics. Finally, in Section 4 we will consider some typical examples how to use this approach to constrain BSM physics combining data from the high-energy as well as the high-precision frontier.

2. Precision tests at the energy frontier

There has been truly impressive progress in theoretical predictions for high-energy scattering processes. Due to a factorization theorem a scattering process can be split into perturbative and non-perturbative parts. This is illustrated in Fig. 1. The parton distribution functions (PDF) give the probability to find a parton with momentum fraction x_i inside a proton of momentum P_i. This is a universal but non-perturbative quantity that is obtained from global fits. The partons then undergo a hard scattering process and produce a number of hard high-energy partons. During the parton shower multiple predominantly soft and collinear radiation is taken into account. The last two parts can be described perturbatively and it is here where there has been tremendous progress in the past few years. For a recent review see for example Ellis et al. [3].

The state of the art for calculating hard scattering processes is roughly $2\to 8$ at LO, $2\to 4/5$ at NLO and there is ongoing work for $2\to 2$ processes at NNLO. NLO calculations are done in a highly automated fashion. Furthermore, several schemes have been worked out to consistently combine NLO calculations with parton showers. This is non trivial, as care has to be taken not to double count the emission of a soft and/or collinear gluon from a hard parton.