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Fundamental Symmetries and Interactions

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In nuclear physics numerous possibilities exist to investigate fundamental symmetries and interactions. In particular, the precise measurements of properties of fundamental fermions, searches for new interactions in β-decays, and violations of discrete symmeties offer possibilities to search for physics beyond standard theory. Precise measurements of fundamental constants can be carried out. Low energy experiments allow to probe New Physics at mass scales far beyond the reach of present accelerators or such planned for the future and at which predicted new particles could be produced directly.

1. Introduction

2. Fundamental Forces and Symmetries

Symmetries play an important and crucial role in physics. Global symmetries give rise to conservation laws and local symmetries yield forces [1]. To date we know four fundamental interactions: (i) Electromagnetism, (ii) Weak Interactions, (iii) Strong Interactions, and (iv) Gravitation. These four forces are fundamental in the sense that all observed dynamical processes in physics can be traced back to one or a combination of them. Together with fundamental symmetries they from a framework on which all physical descriptions ultimately rest.

The Standard Model (SM) is a remarkable theory which allows that Electromagnetic, Weak and many aspects of Strong Interactions can be described to astounding precision in one single coherent picture. It is a major goal in modern physics to find a unified quantum field theory which includes all the four known fundamental forces in physics. On this way, a satisfactory quantum description of gravity remains yet to be found and is a lively field of actual activity.

In this article we are concerned with important implications of the SM and centrally with searches for new, yet unobserved interactions. Such are suggested by a variety of speculative models in which extensions to the present standard theory are introduced in order to explain some of the not well understood and not well founded features in the SM. Among the intriguing questions in modern physics are the hierarchy of the fundamental fermion masses and the number of fundamental particle generations. Further, the electroweak SM has a rather large number of some 27 free parameters. All of them need to be extracted from experiments. It is rather unsatisfactory that the physical origin of the observed breaking of discrete symmetries in weak interactions, e.g. of parity (P), of time

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reversal (T) and of combined charge conjugation and parity (CP), remains unrevealed, although the experimental findings can be well described within the SM.

The speculative models beyond the present standard theory include such which involve left-right symmetry, fundamental fermion compositeness, new particles, leptoquarks, supersymmetry, supergravity and many more. Interesting candidates for an all encompassing quantum field theory are string or membrane (M) theories which in their low energy limit may include supersymmetry.

In the field of fundamental interactions there are two important lines of activities: Firstly, there are searches for physics beyond the SM in order to base the description of all physical processes on a conceptually more satisfying foundation, and, secondly, the application of solid knowledge in the SM for extracting fundamental quantities and achieving a description of more complex physical systems, such as atomic nuclei. Both these central goals can be achieved at upgraded present and novel, yet to be built facilities. In this connection a high intensity proton driver would serve to allow novel and more precise measurements in a large number of actual and urgent issues in this field [2].

Here we can only address a few aspects of a rich spectrum of possibilities.

3. Fundamental Fermions

The Standard Model has three generations of fundamental fermions which fall into two groups, leptons and quarks. The latter are the building blocks of hadrons and in particular of baryons, e.g. protons and neutrons, which consist of three quarks each. Forces are mediated by bosons: the photon, the $W^{\pm}$- and Z^0-bosons, and eight gluons.

3.1. Neutrinos

The leptons do not take part in strong interactions. In the SM there are three charged leptons (e^-, μ^-, τ^-) and three electrically neutral neutrinos (ν_e, ν_μ, ν_τ)) as well as their respective antiparticles. For the neutrinos eigenstates of mass (ν_1, ν_2, ν_3) and flavour are different and connected through a mixing matrix analogous to the Cabbibo-Kobayashi-Maskawa mixing in the quark sector (see 3.2). The reported evidence for neutrino oscillations strongly indicate finite ν masses. Among the recent discoveries are the surprisingly large mixing angles Θ_{12} and Θ_{23} (see [3,4]). The mixing angle Θ_{13}, the phases for CP-violation, the question whether ν's are Dirac or Majorana particles and a direct measurement of a neutrino mass rank among the top issues in neutrino physics.

3.1.1. Neutrino Oscillations

The recent developments in the field of neutrino oscillation research and evidence for such from solar, reactor , atmospheric and accelerator neutrino experiments are reviewed in [3] and [4] in this volume.

3.1.2. Novel Ideas in the Neutrino Field

Two new and unconventional neutrino detector ideas have come up and gained support in the recent couple of years, which have a potential to contribute significantly towards solving major puzzling questions in physics.

(i) The first concept employs the detection of high energetic charged particles originating from neutrino reactions through Cherenkov radiation in the microwave region (or