The Standard Model (L24)

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The Standard Model of particle physics is, by far, the most successful application of quantum field theory (QFT). At the time of writing, it accurately describes all experimental measurements involving strong, weak, and electromagnetic interactions. The course aims to demonstrate how this model, a QFT with gauge group $SU(3) \times SU(2) \times U(1)$ and fermion fields for the leptons and quarks, is realised in nature. It is intended to complement the more general Advanced QFT course. We begin by defining the Standard Model in terms of its local (gauge) and global symmetries and its elementary particle content (spin-half leptons and quarks, spin-one gauge bosons and spin-zero Higgs boson). The parity P, charge-conjugation C and time-reversal T transformation properties of the theory are investigated. These need not be symmetries manifest in nature; e.g. only left-handed particles feel the weak force and so it violates parity symmetry. Ideas of spontaneous symmetry breaking are applied to discuss Goldstone's theorem and the Higgs mechanism. We then describe how the weak and electromagnetic interactions arise from the spontaneous breaking of the $SU(2) \times U(1)$ gauge symmetry. We show how CP violation becomes possible in the electroweak sector when there are three generations of particles and describe its consequences. The topic of neutrino masses and oscillations is touched upon, an important window to physics beyond the Standard Model. We show how to obtain cross sections and decay rates, quantities which can be measured in experiments, from the matrix element of a process. Because the couplings are small, these can be computed for various scattering and decay processes in the electroweak sector using perturbation theory. The strong interaction is described by quantum chromodynamics (QCD), the non-abelian gauge theory of the (unbroken) SU(3) gauge symmetry. At low energies quarks are confined and form bound states called hadrons. The coupling constant decreases as the energy scale increases, to the point where perturbation theory can be used. As an example we consider electron-positron annihilation to final state hadrons at high energies. Time permitting, we may discuss nonperturbative approaches to QCD. Both very high-energy experiments and very precise experiments are currently striving to observe effects that cannot be described by the Standard Model alone. If time permits, we comment on how the Standard Model is treated as an effective field theory to accommodate (so far hypothetical) effects beyond the Standard Model and potential physics beyond the standard model.

Pre-requisites

It is necessary to have attended the Quantum Field Theory and the Symmetries, Fields and Particles courses, or to be familiar with the material covered in them. It would be advantageous to attend the Advanced QFT course during the same term as this course, or to study renormalisation and non-abelian gauge fixing.

Literature

1. M.E. Peskin and D.V. Schroeder, An Introduction to Quantum Field Theory, Addison-Wesley (1995).

2. F. Halzen and A.D. Martin, Quarks and Leptons: An Introductory Course in Modern Particle Physics, Wiley (1984).

3. I.J.R. Aitchison and A.J.G. Hey, Gauge Theories in Particle Physics, CRC Press (two volumes or earlier 1989 edition in one volume).

4. J.F. Donoghue, E. Golowich and B.R. Holstein, Dynamics of the Standard Model, Cambridge University Press (2014).

5. H. Georgi, Weak Interactions and Modern Particle Theory, Benjamin/Cummings (1984).

6. Cliff Burgess and Guy Moore, The Standard Model: A Primer, Cambridge University Press (2012).

7. M. Thomson, Modern Particle Physics, Cambridge University Press (2013).

Additional support

Four example sheets will be provided and four associated examples classes will be given. There will also be a revision class in Easter Term.