Theoretical particle physics

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0 Organisational

Tutorials: Thursday: 8-10, 10-12 Friday: 10-12, 13-15

Exam consists of four problems

- first quickies
- 2nd-4th: similar in style to homework; two will be very close to homework

One needs 50% of points from homework. May hand in pairs.

Content of the lectures

- Standard Model of particle physics
- Electroweak sector
  - gauge principle
  - Higgs mechanism
  - Yukawa interactions
  - CP-violation

Exercises

- go through basics of computing Feynman diagrams
- not to derive the formalism
- Lagrange → Feynman rules → amplitudes → cross section and decay rates (measured quantities)

Literature

- Halzen and Martin, Quarks and Leptons (a lot of basics of QCD)
- Cheng and Li (includes also quantum field theory topics CP-violation in Standard Model)
- Mark Thomson
- QFT basics
  - Peskin and Schroeder
  - M.Schwartz
  - Ryder
- Okun, Leptons and Quarks

1 Introduction

1.1 Standard Model

It is the fundamental theory of nature. There are three interactions included

- electromagnetic
- weak
- strong
- Higgs boson exchange

Electromagnetic and weak interactions can be unified into electroweak interactions.
In the Sun all these three interactions and gravity are present

- Photons reaching us clearly indicate QED's involvement.
- Neutrinos produced in weak interaction. Four protons to two protons and two neutrons (Helium). Only weak interaction can change the colour of quarks.
- Binding of Helium via strong interaction and binding energy released as kinetic energy.
- Gravity brings protons together and at high temperature to give helium.

Gauge theories (Lie groups algebras)

- EM: $U(1)_{EM}$, $U(1)_Y$
- weak: $SU(2)_L$
- strong: $SU(3)_c$

Forces in quantum theories involve exchange particles spin 1, vector bosons

- photon γ
- weak $W^{\pm}$, W^0 and Z^0 (mixture of W^0 and hyper charge) (discovered at CERN)
- strong $g^a, a = 1, \ldots, 8$ gluons (discovered at DESY)

particles with spin $\frac{1}{2}$
Leptons

$$\begin{pmatrix}\nu_e\\ e^-\end{pmatrix}_L, e_R^-; \quad \begin{pmatrix}\nu_\mu\\ \mu^-\end{pmatrix}_L, \mu_R^-; \quad \begin{pmatrix}\nu_\tau\\ \tau^-\end{pmatrix}_L, \tau_R^-$$

Quarks

$$\begin{pmatrix}u\\ d\end{pmatrix}_L, u_R, d_R; \quad \begin{pmatrix}c\\ s\end{pmatrix}_L, c_R, s_R; \quad \begin{pmatrix}t\\ b\end{pmatrix}_L, t_R, b_R$$

One complete generation

$$\begin{pmatrix}\nu_e\\ e^-\end{pmatrix}_L, e_R^-; \quad \begin{pmatrix}u\\ d\end{pmatrix}_L, u_R, d_R;$$

To remove any one part, then gauge theory is inconsistent. It is known as "anomaly". (AQFT)

Higgs boson h^0, spin 0
In Standard Model Higgs bosons are described by complex scalar fields $\begin{pmatrix}H^+\\ H^0\end{pmatrix}$. h^0 is the only fundamental scalar in nature, as far as we know.

1.2 Energy scales

- binding energy of atoms $1 - 10$eV
- binding energy of nucleons $\approx$ 1MeV
- no known binding energy in particle physics
- protons and neutrons $\approx \Lambda_{QCD} \approx O(100\text{MeV})$

Particles have masses

- electron $m_e = 511\,\text{keV}$
- muon $m_\mu = 105\,\text{MeV}$
- tau $m_\tau = 1.7\,\text{GeV}$
- neutrinos $m_\nu < 1\,\text{eV}$
- quarks*
  - $m_u \approx 3\,\text{MeV}$
  - $m_d \approx 5\,\text{MeV}$
  - ...
- photon $m_\gamma = 0$
- gluon $m_g = 0$
- Higgs $m_{Higgs} \approx 125\,\text{GeV}$

*mass of proton mainly comes from dynamical effect "gluon"

Colliders

- LEP 91 GeV − 200 GeV
- Tevatron($p\bar{p}$) 800 GeV − 2 TeV
- LHC 7 TeV − 13 TeV

1.3 Natural units

$$\hbar = c = 1 \tag{1.3.1}$$

$$k_B = 1 \tag{1.3.2}$$

Everything expressed in term of powers of energy.

$$1 = 1 \times 10^{-15}\,\mathrm{m} = 5\,\mathrm{GeV}^{-1}$$