

# Einführung in Theoretische Teilchenphysik

Lecture: PD. Dr. S Gieseke – Exercises: Dr. D. López-Val

## Exercise Sheet 1

Submission: Mo, 23.10.17, 12:00

Discussion: Mon, 23.10.17 11:30 Room 12/1  
Wed, 25.10.17 9:45 Room 10/1

### Exercise 1: Warm up: Natural Units

The so-called *Natural Units* ( $\hbar = c = 1$ ) are commonly employed in Particle Physics. This system of units implies that velocities are measured in units of speed of light  $c$ ; while forces are measured in units of Planck's constant (divided by  $2\pi$ )  $\hbar$ .

- (a) How do Meters (length), Seconds (time), and MeV (energies) relate to each other in this system?

Hint:  $c \approx 2,99 \times 10^8$  m/s, und  $\hbar = 6,58 \times 10^{-22}$  MeV s.

- (b) What is the mass (in Kilogramm) corresponding to 1 MeV?

Hint:  $1\text{eV} = 1,60 \times 10^{-19}$  J.

- (c) Muons  $\mu^\pm$  have a mass of  $m_{\mu^\pm} = 1,88 \times 10^{-28}$  kg and a lifetime of  $\tau_\mu = 2,2 \times 10^{-6}$  s. In turn, the mass of the W bosons is  $m_W = 1,43 \times 10^{-25}$  kg and their corresponding decay rate yields  $\tau_W = 3,1 \times 10^{-25}$  s. Express (in MeV) both the mass and the total decay width  $\Gamma = 1/\tau$  for each particle, and compute the respective width/mass ratios  $\Gamma/m$ . Which of the two particles can you conclude to be more stable?

### Exercise 2: Energy and distance scales

- (a) Estimate the typical length scale that is probed by experiments:  
(i) at the *Large Electron-Positron Collider* (LEP) ( $\sqrt{S} = 45 - 209$  GeV);  
(ii) at the Run II Large Hadron Collider ( $\sqrt{S} = 13$  TeV)

In view of these results: why are the notions of *Particle Physics* and *High Energy Physics* so often used as synonyms?

Hint: Recall the notion of *wave-particle duality* and how it is implemented by the *de Broglie relation*

- (b) Estimate the energy necessary to test the characteristic length scales of a quantum theory of gravitation.

Hint: Use *dimensional analysis*, and bear in mind what are the key scales characterizing *Gravity* ( $G_N = 667408(31) \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$ ); a *quantum regime* ( $\hbar = 6.62607004 \times 10^{-34} \text{ m}^2 \text{ kg s}^{-1}$ ); and *relativistic conditions* ( $c = 299792458 \text{ m s}^{-1}$ ).

### Exercise 3: Range of the fundamental interactions

According to the current paradigm of Particle Physics, the interactions between two particles are described by the exchange of bosonic *force carriers*. These particles can be massive, and in general propagate off-shell ( $p_\mu p^\mu \neq m^2$ ).

- (a) The effective (residual) Strong Interaction between two nucleons is mediated by the interchange of virtual (off-shell) *Pions* ( these are quark-antiquark bound states), and its typical range is of the order of 1 fm. Recalling the Heisenberg uncertainty relations, and assuming that the intermediate pions propagate at the speed of light, estimate the pion mass and compare it to its actual value.
- (b) Using similar arguments, estimate the typical range of:
- (i) The weak interaction (the masses of the  $W$  and  $Z$  bosons are respectively  $M_W \approx 80 \frac{\text{GeV}}{c^2}$  and  $M_Z \approx 91 \frac{\text{GeV}}{c^2}$ ).
  - (ii) The Electromagnetic interaction;
  - (iii) The Strong interaction. Why is your result somehow counterintuitive in the latter case?