# Einführung in Theoretische Teilchenphysik

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

## Exercise Sheet 1

Submission: Mo, 23.10.17, 12:00

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| 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 $\tau_W = 3,1 \times 10^{-25}$. Express (in MeV) both the mass and the total decay decay width $\Gamma = 1/\tau$ for each particle, and compute the respective mass/width ratios $m/\Gamma$. 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* ($G_N = 667408(31) \times 10^{-11}\, m^3\, kg^{-1}\, s^{-2}$)*; a quantum regime* ($h = 6.62607004 \times 10^{-34}\, m^2\, kg\, s^{-1}$)*; and relativistic conditions* ($c = 299792458\, m\, s^{-1}$)*.*

### 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 $W$ und $Z$ 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?