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Übungen zu Teilchenphysik I

Wintersemester 2024/25

Exercise 3 To be worked on until November 28, 2024

To start with the exercise, please login to the jupytermachine, start the standard `Datenanalyse` container and update your `tp1_forstudents` repository, e.g. by navigating to the directory in the file browser on the left and then selecting `Git -> Pull from Remote` from the menu bar. A new subfolder `Exercise04` should appear with a Jupyter notebook `Exercise04.ipynb`. Open this notebook and do the different exercises.

Since we're going to ask you to do some calculations, it's up to you whether you write the "heavy" calculations in the notebook or not: it's fine if you don't write them down in the notebook, but show us on paper.

1 A massive scalar... photon?

Let's imagine a parallel universe in which the photon, instead of being a massless vector particle (spin-1), is a massive scalar particle (spin-0). The QED vertex in the Feynman rules in this theory would be $-ig_e I$, where I is the 4×4 unit matrix (to compare with $-ig_e\gamma^\mu$ for the massless vector photon). There would also be no factors for the outer photon lines, since there is no photon polarisation.

1. Assuming that this "photon" is heavy enough to decay into a pair of Standard Model particles, calculate the decay rate Γ for $\gamma \to e^+e^-$ using the helicity spinors (in the centre-of-mass frame). Neglect the electron/positron mass in this calculation.

2. Is helicity "conserved" in high-energy interactions in this theory? Explain how this differs from QED.

3. Do the calculation again, but this time include the electron/positron mass.

4. If $m_\gamma = 3$ GeV, calculate the lifetime of this "photon" in seconds.

2 Muon decay

Let's consider the muon decay $\mu^- \to \nu_\mu \bar{\nu}_e e^-$, which is described by the S=standard model's electroweak interaction lagrangian.

1. Draw the first-order Feynman diagram describing muon decay; consider $m_W \gg m_\mu$ and derive the effective lagrangian (also called the Fermi lagrangian), showing the relationship between the electroweak coupling constant g_W and the Fermi constant G_F.

2. Using the Fermi lagrangian, calculate the decay rate of the muon and its lifetime.

3. Using the derived formula for muon decay, calculate the lifetime of the τ lepton and compare it with the measured value (check the most recent value on PDG). Are there any differences between the calculated and the measured value? Why are there differences?