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Experimental physics Vb (particle and astro-physics)

Exercise 05

Task 1 *Electron-muon-scattering* (4 points)

Consider electron-muon-scattering $e^+ + e^- \to \mu^+ + \mu^-$ in the context of QED, such that the differential cross section is given by

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \frac{\alpha^2}{4s}(1+\cos^2\theta).$$

How many muon pairs are created at a center-of-mass energy of $\sqrt{s} = 34\,\mathrm{GeV}$ and a luminosity of $5 \times 10^{30}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ per second inside the central region (scattering angle between 45° and 135°)?

Task 2 *Electric dipole moment of the neutron* (3 points)

Show that a permanent electric dipole moment of the neutron, which has a magnetic moment, violates both P and T symmetry (and hence from conservation of CPT violates also CP symmetry).

Task 3 *CKM matrix* (1+2+4+3+2=12 points)

As given in the lectures, let the CKM matrix be defined by

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}\mathrm{e}^{-\mathrm{i}\delta} \\ 0 & 1 & 0 \\ -s_{13}\mathrm{e}^{\mathrm{i}\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix},$$

where $s_{ij} \equiv \sin\theta_{ij}$ and $c_{ij} \equiv \cos\theta_{ij}$.

a. Show that V_{CKM} is a unitary matrix.

b. Derive the closed form of V_{CKM}.

c. Use the definitions

$$s_{12} = \lambda, \qquad s_{23} = A\lambda^2, \qquad s_{13}\mathrm{e}^{-\mathrm{i}\delta} = A\lambda^3(\rho - \mathrm{i}\eta)$$

to derive the Wolfenstein parameterization shown in the lectures, up to order $\mathcal{O}(\lambda^4)$.

d. Prove that the relations

$$s_{12} = \lambda = \frac{|V_{us}|}{\sqrt{|V_{ud}|^2 + |V_{us}|^2}}, \qquad s_{23} = A\lambda^2 = \lambda\left|\frac{V_{cb}}{V_{us}}\right|, \qquad s_{13}\mathrm{e}^{\mathrm{i}\delta} = V_{ub}^* = A\lambda^3(\rho{+}\mathrm{i}\eta)$$

follow both from the closed form and from the Wolfenstein parameterization.

e. Prove that the tip of the unitary triangle defined in the lectures lies indeed at (ρ,η), or $(\bar{\rho},\bar{\eta})$ respectively, in the complex plane.

Task 4 *Decay of the D^0 meson* (3+3=6 points)

a. Explain why the probability for a D^0 meson ($c\bar{u}$) to decay to $K^-\pi^+$ is much larger than to $K^+\pi^-$. Draw the corresponding Feynman diagrams!

b. Perform a rough estimation of the ratio of the two relative decay widths. Compare to the experimental data.