# 08.128.742 Quantum Field Theory III
# The Standard Model and Electroweak Theory

**Homework set 5**

**Due January 28, 2021; e-mail (photo or scan) to yu001@uni-mainz by start of discussion session**
**Please note how long it took you to solve each problem**

5-1, 40 pts. The penguin diagram. (A) Draw the 1-loop Feynman diagram for a transition of $b \to s\mu^+\mu^-$. (B) Draw the 1-loop Feynman diagram for $K^+ \to \pi^+\nu\bar{\nu}$ and $K_L \to \pi^0\nu\bar{\nu}$. (C) Draw the lowest order diagram for the $\mu \to e\gamma$ decay in the Standard Model, and also draw the $\mu \to 3e$ diagram. (D) How are all of these diagrams (A)-(C) related? What is the phenomenology of the penguin diagram? Estimate the branching fractions of (A)-(C) and compare with the SM experimental measurements or current exclusions. *Note:* The $B_s \to \mu^+\mu^-$ decay was one of the landmark measurements of the LHCb and CMS experiments at the LHC. Initial announcements were made in 1307.5024 (LHCb) and 1307.5025 (CMS), while a more recent analysis with more statistics can be found in 1703.05747. *Also note:* The $K \to \pi\nu\nu$ measurement is the primary motivation for the NA62 and KOTO experiments. There was initially some excitement about an excess in the KOTO dataset, but the reanalysis (after data unblinding) has increased the background estimate, which can be seen in 2012.07571. *Final note:* The $\mu \to e\gamma$ decay is the hallmark measurement of the MEG experiment, which concluded its physics run in 2013 and released a limit of $4.2 \times 10^{-13}$ at 90% C.L. The analysis can be found in 1605.05081. MEG2 aims to improve the sensitivity by an order of magnitude.

5-2, 60 pts. Glashow-Iliopoulos-Maiani (GIM) mechanism. (A) Draw the 1PI diagrams for the decay of $\bar{K}_0 \to \mu^+\mu^-$. If we restrict to a 2-generation set of up and down quarks, what is the prediction for the decay width for $\bar{K}_0 \to \mu^+\mu^-$? Relate this result to the structure of flavor symmetry in the 2-generation Standard Model. *Note:* This is the original calculation that led to the prediction of the charm quark. (B) Draw the 1PI diagrams for $B_0 \to \bar{B}_0$ oscillation. We will take the full SM with 3 generations of quarks. The easiest approach to evaluate the diagrams comes from setting the external momenta to zero and neglecting the light quark masses, including the bottom mass. Construct the expression for the mass difference between the $B$-meson mass eigenstates, in analogy to the $K_L - K_S$ mass difference.