PHY493/803 Spring 2025, Intro to Elementary Particle Physics

Homework 1 - Due Date 27th of January.

Please clearly state any assumptions, show all your work, number the equations, and indicate logical connections between the lines.

1. (3pt x 8)

   Decays of fundamental particles (particles with no internal structure) that are on-shell (mass corresponds to their rest mass) must strictly follow conservation rules. One of the following decays is allowed and the rest violate at least one conservation rule. For each process, list all violated conservation rules or identify it as allowed and state what interaction is responsible. Consider: energy conservation, charge conservation, lepton number and flavor, baryon number, quark flavor.

   (a) $\gamma \rightarrow e^- + \mu^+$

   (b) $W^+ \rightarrow t + \overline{b}$

   (c) $Z^0 \rightarrow \mu^+ + \mu^+$

   (d) $t \rightarrow W^+ + b$

   (e) $W^- \rightarrow e^- + \nu_e$

   (f) $\gamma \rightarrow \tau^- + \tau^+$

   (g) $b \rightarrow c + e^-$

   (h) $\overline{b} \rightarrow Z + \overline{s}$

2. (3pt x 6)

   Decays of hadrons (particles made up of quarks) can proceed via many different processes. Evaluate the following reactions and determine which are physically possible. Draw Feynman diagrams at the quark level for the reactions that are allowed. For those that are forbidden, what conservation laws are violated? If the reactions are allowed, which interactions (strong, weak, and electromagnetic forces) should be involved? Please find more

information on these particles in the PDG:
https://pdg.lbl.gov/2024/listings/contents_listings.html,
https://pdg.lbl.gov/2024/tables/contents_tables.html.

(a) $\Omega^- \rightarrow \Xi^- + \pi^-$

(b) $\Sigma^+ \rightarrow \pi^+ + \pi^0$
(c) $\pi^0 \rightarrow \mu^+ + e^- + \bar{\nu}_e$
(d) $D^- \rightarrow K^+ + \pi^- + \pi^-$
(e) $p + \bar{p} \rightarrow \pi^- + \pi^+$
(f) $p \rightarrow e^+ + \gamma$

3. (20pt)
What would be the approximate counting rate observed in the Rutherford scattering of 10 MeV alpha particles off gold foil at an angle of π/4 in the laboratory? Assume an incident flux of 10^5 alpha particles per second on the foil, a foil of 0.1 cm thickness, and a detector of transverse area 1 cm x 1 cm placed 100 cm from the interaction point, the atomic (mass) number of gold of 79 (197), and the density of gold of 19.7 g/cm^3.

4. (5 pt + 15 pt) **{Required for PHY803 students only. +10 pts extra credit for PHY493 students.}**

A) The $\Lambda^0(1116)$ is a hadronic resonance with mass 1116 MeV. Explain why the decay $\Lambda^0 \rightarrow p + \pi^-$ is allowed, but $\Lambda^0 \rightarrow \pi^+ + \pi^-$ is not.

B) Some of the decays listed in problem 1 actually do occur at the LHC at CERN where they are part of a more extensive Feynman diagram in a collisions, or at b-factories as part of a particle decay Feynman diagram. Identify which decays these are, explain what condition needs to be fulfilled, and give an example Feynman diagram for each production and decay process.