Massachusetts Institute of Technology

Department of Physics

Course:	8.701 — Introduction to Nuclear and Particle Physics
Term:	Fall 2020
Instructor:	Markus Klute

Problem Set 3

handed out October 7th, 2020

Electron-positron annihilation and pair production

Problem 1: Helicity combinations [20 points]

To calculate the $e^+e^- \to \mu^+\mu^-$ cross section, the matrix element needs to be evaluated taking all possible spin states into account. Draw all possible initial state helicity combinations. How many helicity combinations are there in total?

Problem 2: Spinor [20 points]

Show the four-momenta of the initial and final state particles in $e^+e^- \to \mu^+\mu^-$ in the limit where masses of particles can be neglected. Without loss of generality, take μ^+ and μ^- to be produced with azimuthal angles of $\phi = 0$ and $\phi = \pi$, respectively. Give all spinors for the initial and final state particles and lable the helicity configuration.

Problem 3: Currents [20 points]

The matrix element for a particular helicity combination is $M = -\frac{e^2}{s} j_e \cdot j_\mu$ with s being the four times the beam energy and j_e and j_μ the four vector currents. The muon current, $j_\mu^\nu = \bar{u}\gamma^\nu v$, needs to be evaluate for the possible helicity combinations. Find the four components of the muon current for all helicity combinations. Which combinations yield non-zero four-vector currents? Repeat the discussion for the electron currents.

Problem 4: Spin [20 points]

Define the z-axis to be the direction of the incoming electron beam. What are the spins of the combined spins of the e^+ and e^- for the non-zero matrix elements? Express the spin states of the $\mu^+\mu^-$ system in terms of the eigenstates of spin-operator $\hat{S}_z = \frac{1}{2}\Sigma_z$.

Problem 5: Photon Decay [20 points]

Consider the following process $e^+e^- \to \gamma\gamma$. Discuss the kinematics of this process with four-momenta. What can you say about the spin configuration and the photon current?

8.701 Introduction to Nuclear and Particle Physics
Fall 2020