Final

1) What are three major consequences of combining QM and Relativity? *(3 points)*

2) Lorentz Transforms *(5 points)*

a) How does a massive particle $|p^{\mu}, \sigma\rangle$ transform under a little group transformation (W^{ν}_{μ}) ?

d) How does a mass-less particle $|p^{\mu}, \sigma\rangle$ transform under a little group transformation (W^{ν}_{μ}) ?

c) How does a massive particle $|p^{\mu}, \sigma\rangle$ transform under a general Lorentz transformation (Λ^{ν}_{μ}) ?

d) How does a mass-less particle $|p^{\mu}, \sigma\rangle$ transform under a general Lorentz transformation (Λ^{ν}_{μ}) ?

3) List or draw a diagram of the particles in the Standard model. *(3 points)*
What is the spin of each particle ?

4) Why is the weak interaction so much weaker than the electromagnetic interaction at low energies? *(2 points)*

5) Accelerators: *(4 points)*

a) What limits the energy of circular proton accelerators ?

b) What limits the energy of circular electron accelerators ?

6) Muon decays: *(10 points)*

a) The muon decays via the weak interaction. At low energy ($E << m_W$), this can be approximated as a point-like interaction. Draw the diagram describing muon decay to an electron assuming a point-like weak interaction.

b) What are the dimensions of the coupling constant, associated to this diagram ?

c) How does the decay rate Γ (decays/unit time) depend on the muon mass ?

d) The muon has a mass of ~0.1 GeV and a lifetime of $\sim 1\mu s$. The tau lepton has a mass of ~1 GeV. Estimate the lifetime of the tau lepton in μs.

e) Suppose that the photon could couple at the same vertex to the muon and the electron. Then the muon could decay as $\mu \to e\gamma$. Estimate the ratio of the μ lifetime in this world to that in our world without this interaction.

7) Electron-positron Collisions *(10 points)*

a) Consider electron-positron collisions with a center-of-mass energy of 40 GeV. Estimate the ratio of hadron production to di-muon production.

b) Sketch a graph of the total cross section of $ee \to \mu\mu$ as a function of E_{CM} from 40 GeV to 200. Also sketch the component of the cross section due to the electro-magnetic interaction.

8) Branching ratios: *(9 points)*

a) How often does a τ decay to a charged lepton ?

b) How often does a Z-boson decay to charged leptons ?

c) How often does a W-boson decay to a charged lepton ?

9) Collider Detectors *(6 points)*

a) In what ways do the detector signatures of electrons and muons look a-like, in what ways are they different ?

b) In what ways do the detector signatures of electrons and photons look a-like, in what ways are they different ?

10) What are some reasons that hadronic showers are more challenging to measure than electro-magnetic showers ? *(5 points)*

11) If you want to improve momentum resolution, is it better to have a tracking detector that is twice as big or that has twice the magnetic field ? Justify your answer. *(5 points)*

12) For a new particle X with mass ~ 2 TeV, would you expect to measure the X mass more precisely from $X \to ee$ or $X \to \mu\mu$? Justify your answer. *(5 points)*

13) How are νs detected at the LHC ? *(3 points)*

14) Spontaneous Symmetry Breaking *(9 points)*

a) What is the particle spectra (ie: for each particle, is it massive or mass-less and what is the spin) from the Lagrangian:

$$\mathcal{L} = (\partial_\mu \phi^*)(\partial^\mu \phi) - V(\phi), \text{ where } \phi = \phi_1 + i\phi_2, \; V(\phi) = \mu^2 \phi^* \phi + \lambda(\phi^* \phi)^2 \text{ and } \lambda, \mu^2 > 0$$

b) What is the particle spectra from the setup in a) but with $\mu^2 < 0$?

c) What is the particle spectra from the Lagrangian:

$$\mathcal{L} = (D_\mu \phi^*)(D^\mu \phi) - V(\phi) - \frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$

where ϕ and $V(\phi)$ are as before, $D_\mu = \partial_\mu - ieA_\mu$, $\lambda > 0$, and $\mu^2 < 0$?

15) Higgs Physics *(7 points)*

a) Estimate the ratio of Br($H \to \mu\mu$)/Br($H \to \tau\tau$)

b) Draw one possible Feynman diagram for production and decay of the Higgs boson at the LHC.

c) Draw one possible Feynman diagram for the possible and decay of the Higgs boson at an electron -positron Collider.

16) What are some experimental constraints on a fourth generation of leptons ? *(3 points)*

17) Neutrino Physics *(17 points)*

a) How was the distinction between ν_μ and ν_e discovered ?

b) Why was this expected ?

c) What was the main reason to study νs in the 60s and 70s, before we knew they had mass?

d) What are dominant kind(s) (indicate particle or anti-particle and flavor) of νs that are produced (ignore oscillations) from:

i) The sun ?

ii) Nuclear reactors ?

ii) Cosmic-rays ?

iv) ν-beams ?

18) In a two ν model, what combination of Δm^2, E, and L do the transition probabilities depend on? *(3 points)*

19) What problems might Super-Symmetry solve ? *(3 points)*