# 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 ($W_{\mu}^{\nu}$) ?

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

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

d) How does a mass-less particle $|p^\mu, \sigma\rangle$ transform under a general Lorentz transformation $(\Lambda^\nu_\mu)$ ?

**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) 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. (Indicate which is the XXX

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

c) How does the decay rate $\Gamma$ (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 $\mu s$.

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 $\mu$ lifetime in this world to that in our world without this interaction.

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

**7) What problems might SuperSymmetry solve ?** *(3 points)*

**8) Muon Neutrinos** *(3 points)*

a) How was the distinction between $\nu_\mu$ and $\nu_e$ discovered ?

b) Why was this expected ?

**9) Accelerators:** *(3 points)*

a) What limits the energy of circular proton accelerators ?

b) What limits the energy of circular electron accelerators ?

**10) Electron-positron Collisions** *(3 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 compent of the cross section due to the electro-magnetic interaction.

**11) Spontaneous Symmetry Breaking** *(3 points)*

What particle spectra would you expect from $L = (dP)^2 + mu^2$+ V w mu2 > 0 V w mu2 < 0 U(1) + V mu2 < 0

**12) Leptons** *(3 points)*

Branching ratios: $\tau \rightarrow eor\mu$

**13) Collider Detectors** *(3 points)*

In a collider experiment at the LHC,

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 ?

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

**14) Why are hadronic showers more challenging to measure than electro-magnetic showers ?** *(3 points)*

**15) Other things being equal is it better to have a tracking detector that is twice as big or that has double the magnetic field ? Justify your answer.** *(5 points)*

**16) How are $\nu$s detected at the LHC ?** *(3 points)*

**16) Higgs Physics** *(3 points)*

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

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

c) Draw one possible feyman diagram for the possible and decay of the Higgs boson at an eletron -positron collider.

**16)** *(3 points)*

**16) Neutrino Physics** *(10 points)*

a) What was the main reason to study $\nu$s in the 60s and 70s, before we knew they had mass?

b) What are dominant kind (indicate particle or anti-particle and flavor) of $\nu$sthat come from:

   i) The sun ?

ii) nuclear reactors ?

ii) cosmic rays ?

iv) nu beams ?