Physics 152/252 Final Exam

Take Home, due at noon Wednesday June 11, in Marc Schreiber's Varian mailbox

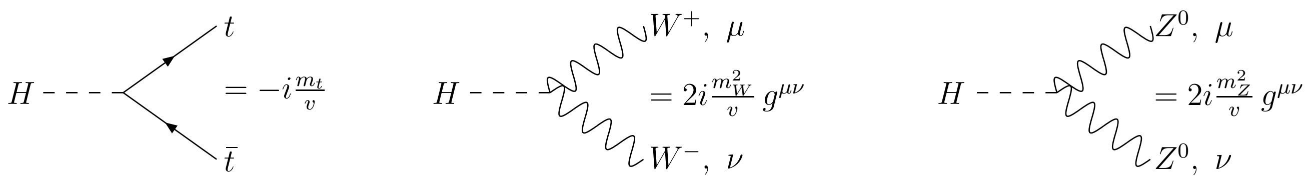
Ground rules: You may use a calculator, Griffiths, *Introduction to Elementary Particles*, as well as your personal class lecture notes, and any of the lecture notes at `http://www.slac.stanford.edu/~lance/phys152`
Otherwise you are on your own: you may not use any other books, people, papers, or Web material.

Problem 1 (25 pts): Another kind of particle beam contemplated for future high energy colliders is a photon beam. The most feasible way proposed to produce photons with energies in the GeV to TeV range is to use the Compton process, $\gamma e \to \gamma e$, by scattering a laser beam off a high energy electron beam. Let the electrons have energy E_e and the photons have energy E_γ. Assume $E_e \gg m_e$. However, do *not* assume $E_e E_\gamma \gg m_e^2$. What is the center-of-mass energy of the collision? What scattering angle in the center-of-mass frame gives rise to the maximum photon energy in the lab frame? What is this maximum photon energy? Suppose the laser beam is near-infrared light, with a wavelength of 1.06 microns. What are the numerical values of the maximum photon energy for an incident electron energy of 50 GeV? 250 GeV?

Problem 2 (20 pts): The total cross section $\sigma_{\nu N}(s)$ for neutrinos interacting with nucleons, for center-of-mass energies $\sqrt{s}$ below m_W, is given roughly by dimensional analysis as $\sigma_{\nu N}(s) = G_F^2 s$. Here the Fermi constant $G_F = 1.2\times 10^{-5}$ GeV^{-2}. Estimate the mean free path ℓ_ν for 1 GeV neutrinos traversing the Earth, in units of Earth diameters, $d_E = 1.3 \times 10^4$ km. (The mass of the Earth is $m_E = 6 \times 10^{24}$ kg.) For what neutrino energy E_ν does the Earth begin to become opaque; *i.e.*, when does $\ell_\nu(E_\nu) = d_E$? (Assume that $\sigma_{\nu N}(s) = G_F^2 s$ continues to hold at such energies.)

Problem 3 (20 pts): In class we computed the differential cross section for $e_R^+ e_L^- \to b\bar{b}$ on top of the Z resonance, with polarized initial electrons (as measured at SLD): $d\sigma(e_R^+ e_L^- \to Z \to b\bar{b})/d\cos\theta$. Compute the same differential cross section for *un*polarized initial beams (as measured at LEP), $d\sigma(e^+e^- \to Z \to b\bar{b})/d\cos\theta$, ignoring overall, θ-independent factors. What is the unpolarized forward-backward asymmetry, $A_{FB}^b \equiv [\int_0^1 d\cos\theta \frac{d\sigma}{d\cos\theta} - \int_{-1}^0 d\cos\theta \frac{d\sigma}{d\cos\theta}] / \int_{-1}^1 d\cos\theta \frac{d\sigma}{d\cos\theta}$?

Problem 4 (35 pts): Suppose the Standard Model Higgs boson H has mass $m_H > 2m_t$. (Precision electroweak data do not allow a mass this large in the Standard Model, but never mind.) In this case, its dominant decay modes are to pairs of top quarks ($t\bar{t}$) and vector bosons (W^+W^- or ZZ). Work out the partial decay widths for each of these cases, $\Gamma(H \to t\bar{t})$, $\Gamma(H \to W^+W^-)$, and $\Gamma(H \to ZZ)$. For this you will need the Feynman rules:



where v is the Higgs vacuum expectation value, $v = 246$ GeV. As for the scalar A, B, C theory in Chapter 6 of Griffiths, there is no external line factor for the scalar H. The sum over massive vector boson polarization states produces a transverse projection operator,

$$\sum_{\lambda=-1,0,1} \varepsilon_\lambda^\mu(q)\varepsilon_\lambda^{\nu *}(q) = -(g^{\mu\nu} - q^\mu q^\nu / M^2),$$

where q^μ is the vector boson momentum, and M its mass. Using your three partial width formulas, work out for $m_H = 400$ GeV the total width of the Higgs boson (in GeV), and its branching ratios into each of $t\bar{t}$, W^+W^- and ZZ. Use $m_W = 80$ GeV, $m_Z = 91$ GeV, $m_t = 175$ GeV.