Schwartz: Collider Physics

Problems

1. How much energy is in the LHC beam, in Joules (1 J = 6.2×10^{18} eV)?

2. Show that pseudorapidity differences are *not* boost invariant for massive particles. Calculate the dependence of $\eta_1 - \eta_2$ on the masses of two massive particles to leading non-vanishing order in the masses.

3. The boost parameter β, with $\cosh \beta = \frac{1}{1-v^2}$ is also sometimes called the rapidity. Derive a relationship between the rapidity y and β for a particle of mass m moving with velocity v in the z direction.

4. ATLAS currently has high-resolution tracking information up to $|\eta| < 2.5$, but is considering extending it up to $|\eta| < 4$ in the next long upgrade. Suppose1000 Z bosons are produced at rest at the LHC and then decay to $\mu^+\mu^-$. How many of the events would have both muons leave tracks in the inner tracker with the current ATLAS setup and after the upgrade?

5. One of the goals of a future e^+e^- collider would be to study Higgs properties.

   (a) Estimate the cross section for $e^+e^- \to \mu^+\mu^- b\bar{b}$ through a Zh intermediate state at center-of-mass energies 100 GeV, 200 GeV and 300 GeV.

   (b) Current designs for an e^+e^- Higgs factory aim to run at 240 GeV. What are the tradeoffs in running at higher and lower energy that might make this the optimal energy?

6. Consider a W boson decaying to an electron e^- and a neutrino ν. For the electron, we measure the longitudinal momentum p_e^z and transverse momentum $\vec{p}_e^T$ and for the neutrino, just the transverse momentum $\vec{p}_\nu^T$ which we get from missing transverse momentum $\vec{\not{p}}_T$ in the event: $\vec{p}_\nu^T = -\vec{\not{p}}_T$. The transverse energy of the electron and neutrinos are defined as $E_T^e = \sqrt{m_e^2 + (\vec{p}_e^T)^2}$ and $E_T^\nu = |\vec{\not{p}}_T|$. Show that the transverse mass, defined as

$$M_T = \sqrt{\left(E_T^e + E_T^\nu\right)^2 - \left(\vec{p}_e^T + \vec{p}_\nu^T\right)^2} \tag{1}$$

   is less than or equal to the W boson mass.

7. Suppose there were four flavors of light neutrinos instead of three. What would the Z width be in this case? Put a bound on the number of massless neutrinos using that $\Gamma_Z = 2.4952 \pm 0.0023$ GeV.

8. Consider the process $pp \to t\bar{t}h$.

   (a) What fraction of events has $1, 2, 3$ or 4 b-jets in it.

   (b) What is some of the largest backgrounds to in the fully leptonic decay mode (i.e. tops decay leptonically, Higgs decays to $b\bar{b}$)?

   (c) Consider the fully hadronic channel, with both tops decaying to jets. Estimate the fraction of events in which *all* of the jets are in the central region ($\eta < 3$).

   (d) How much p_T does the Higgs need for the typical distance between the b jets from its decay to be within $\Delta R < 1$?