PHZ 6358: Standard Model I  
Fall Term 2015  
Homework Set 6

Due Wednesday, December 2, 2015

Reading: PYTHIA manual, as needed.

**Problem 1. Particle rapidity.** The rapidity $y$ of a particle of mass $M$ and 4-momentum $P^\mu = (E, p_x, p_y, p_z) = (E, \vec{p}_T, p_z)$
is defined as

$$y = \frac{1}{2} \ln \frac{E + p_z}{E - p_z}.$$  

(a) Show that the 4-momentum can be written as

$$P^\mu = \left( e_T \cosh(y), p_T \cos(\varphi), p_T \sin(\varphi), e_T \sinh(y) \right),$$

where $e_T = \sqrt{M^2 + p_T^2}$ and $\varphi$ is the usual azimuth angle.

(b) Show that the phase space element can be expressed as

$$\frac{d^3 \vec{p}}{E} = p_T dp_T d\varphi dy = e_T d\varphi dy.$$  

**Problem 2. PYTHIA simulations.** Use PYTHIA to simulate some of the processes which we have already considered. Set up the LHC at 13 TeV, and record the cross-sections for:

(a) the Higgs 4-lepton channel, $pp \rightarrow h \rightarrow ZZ^* \rightarrow 4\ell$

(b) dilepton $t\bar{t}$ production

(c) Single $W$ production in the leptonic channel

(d) Drell-Yan

(e) $Wh$ production followed by $W \rightarrow \ell \nu$ and $h \rightarrow b\bar{b}$.  

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