Problem Set for Hadron Collider Physics 2015

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Problem Set 3

Your solutions have to be handed in by 10:10 am on Tuesday, May 19th 2015. Please drop them into the mailbox number 1 on the ground floor of the Gustav-Mie building!

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1. **Kinematic variables**

   At a hadron collider, if a massive particle decays into a lepton and a neutrino, its invariant mass cannot be reconstructed, as the longitudinal component of the neutrino momentum cannot be measured.

   (a) How is the transverse momentum of the neutrino measured? **[1 point]**

   A useful variable to consider is the transverse mass m_T, defined as:

   $$m_T{}^2 = (E_T(1) + E_T(2))^2 - (\mathbf{p}_T(1) + \mathbf{p}_T(2))^2 \tag{1}$$

   (b) Derive a simplified formula for the transverse mass in the approximation $m_1 = m_2 = 0$ **[1 point]**

   We now consider a W boson with mass $m_W = 80$ GeV and its decay $W \to e\nu$ (there is no need here to distinguish the $W^+ \to e^+\nu$ and the $W^- \to e^-\bar{\nu}$). Assume that the W is produced at rest.

   (c) Determine the differential distribution dN/dm_T and its dependency on m_W. Show that the distribution has an end point at $m_T = m_W$ **[3 points]**
   [HINT: the following identity

   $$\frac{dN}{dm_T} = \frac{dN}{d\Omega}\frac{d\Omega}{dm_T} \tag{2}$$

   can be useful.]

2. **Minimum bias interactions**

Using what you have learned in the previous problem set, you can now generate with `Pythia` events and store them in `ROOT ntuples`. First, generate 10^5 events of non-diffractive proton-proton collisions at a center-of-mass energy of 900 GeV. Save the final state particles into your `ROOT ntuple`. Repeat the same thing, but this time, set the center-of-mass energy to 7 TeV. Save these events into a different `ROOT ntuple`. For each of these two files:

(a) Write down the cross section for this process. You can find it in the log file that `Pythia` produced. [**1 point**]

(b) What integrated luminosity do the 10^5 events correspond to in each case? [**1 point**]

(c) Investigate the particle spectrum. What is the average composition of particles with $p_T > 100$ MeV? [**2 points**]

(d) Where do all those photons come from mainly? Is the fraction of $\pi^{\pm}$ with respect to π^0 roughly in agreement with what you expect from isospin symmetry? [**2 points**]

(e) Plot the following distribution of charged particles with $p_T > 100$ MeV and $|\eta| < 2.5$ (be careful with the normalization):

$$\frac{1}{N_{ev}}\frac{dN_{ch}}{d\eta} \qquad \frac{1}{N_{ev}}\frac{1}{2\pi p_T}\frac{d^2N_{ch}}{dp_T d\eta} \qquad \frac{1}{N_{ev}}\frac{dN_{ev}}{dn_{ch}} \tag{3}$$

where N_{ev} is the number of event, N_{ch} is the number of charged particles, n_{ch} is the number of charged particles per event. [**2 points per distribution**]

[**Bonus questions:**] Address also the following items:

(f) What is the average charged particle multiplicity (with $p_T > 100$ MeV) at $\eta = 0$ in each center-of-mass point? Produce the relevant figures to answer this question. [**2 bonus points**]

(g) Compare the results with those shown in `http://arxiv.org/pdf/1012.5104v2` and briefly discuss possible sources of differences between these published results and your own results. [**2 bonus points**]