Particle Physics Phenomenology exercise 6

1. a) Do a toy Monte Carlo "shower" simulation, using the veto algorithm, to estimate how the average x value of a quark decreases in the evolution towards higher Q scales by initial-state radiation of gluons. To be specific, assume an initial $x_0 = 0.5$ at $Q_0 = 1$ GeV and evolve to $Q = 100$ GeV for a fix $\alpha_{\mathrm{s}} = 0.15$. Compare the result when you regularize the $q \to qg$ splitting kernel at a $z_{\mathrm{max}} = 0.9$, 0.99 and 0.999.
   Hint: You may reuse parts of the expressions from exercise 3.3, but note that the evolution now goes towards larger Q scales.
   (b) Compare the result you obtain with the analytic result of exercise 4.4.

2. Assume that bunch crossings at the LHC are uniform (same number of protons per bunch, same impact-parameter profile), so that the "pileup" number of pp collisions μ per crossing is described by a Poissonian with average $\langle \mu \rangle$:

$$P_i = \frac{\langle \mu \rangle^i}{i!} \exp(-\langle \mu \rangle) \ .$$

   a) What is the distribution of pileup events in those crossings where a Higgs is produced?
   Hint: View the Higgs cross section as a vanishingly small fraction ϵ of the total cross section. Then a (binomial) expansion of $((1-\epsilon)+\epsilon)^i$ allows you to pick up the terms related to the production of exactly one Higgs.
   b) A similar argumentation can be used for the number of MPIs in a single pp collision where a Higgs is produced. The difference is that the multiplicity distribution is much broader than a Poissonian, owing to the impact-parameter dependence. As a simple example, consider a geometrical distribution

$$P_i = \frac{\langle \mu \rangle^i}{(\langle \mu \rangle + 1)^{i+1}} \ .$$

   What distribution is then obtained for the number of additional MPIs? What are the implications, relative to the Poissonian case?
   Hint: The binomial-expansion result above is still valid.

3. a) Study the properties of nondiffractive events at LHC at 8 TeV,
   `SoftQCD:nonDiffractive = on`,
   e.g. the charged multiplicity distribution $\mathrm{d}P/\mathrm{d}n_{\mathrm{ch}}$, the pseudorapidity distribution $\mathrm{d}n_{\mathrm{ch}}/\mathrm{d}\eta$, the transverse momentum distribution $\mathrm{d}n_{\mathrm{ch}}/\mathrm{d}p_{\perp}$, and the average transverse momentum as a function of multiplicity $\langle p_{\perp} \rangle (n_{\mathrm{ch}})$.
   b) How are these distributions changed if MPIs are switched off,
   `PartonLevel:MPI = off`?
   c) How are the distributions instead changed if colour reconnection is switched off,
   `ColourReconnection:reconnect = off`?

4. Extend the exercise above with a study of forward–backward correlations. To this end, select two symmetrically located, one unit wide bins in rapidity (or pseudorapidity), with a variable central separation Δy: $[\Delta y/2, \Delta y/2+1]$ and $[-\Delta y/2-1, -\Delta y/2]$. For each event you may find n_F and n_B, the charged multiplicity in the "forward" and "backward" rapidity bins. Suitable averages over a sample of events then gives the forward–backward correlation coefficient

$$\rho_{FB}(\Delta y) = \frac{\langle n_F \, n_B \rangle - \langle n_F \rangle \langle n_B \rangle}{\sqrt{(\langle n_F^2 \rangle - \langle n_F \rangle^2)(\langle n_B^2 \rangle - \langle n_B \rangle^2)}} = \frac{\langle n_F \, n_B \rangle - \langle n_F \rangle^2}{\langle n_F^2 \rangle - \langle n_F \rangle^2} \ ,$$

where the last equality holds for symmetric distributions such as in pp and $\overline{\mathrm{p}}$p. Compare how $\rho_{FB}(\Delta y)$ changes for increasing $\Delta y = 0, 1, 2, 3, \ldots, 8$, with and without MPI switched on.