Particle Physics Phenomenology exercise 8

1. Calculate the invariant mass of two massless four-vectors with fixed $E_{\perp 1}$ and $E_{\perp 2}$ and a given separation $\Delta\eta$ and $\Delta\phi$. Show that, for small separations, this invariant mass only depends on R, rather than on $\Delta\eta$ and $\Delta\phi$ separately.
   Hint: recall exercise 2.1.

2. a) Find the jets in QCD two-jet events with a hard scattering above 250 GeV, at 13 TeV LHC. Use both the anti-$k_\perp$, Cambridge/Aachen and $k_\perp$ algorithms, with $R = 0.5$ and $p_{\perp\mathrm{min}} = 20$ GeV. Compare average number of jets and average $p_\perp$ of the hardest jet. Also study event-by-event the difference in hardest jet $p_\perp$ between any two of the jet algorithms.
   b) Repeat the same exercise for top pair production.
   Hint 1: `HardQCD:all = on` and `PhaseSpace:pTHatMin = 250.` for hard QCD jets, and `Top:gg2ttbar = on` and `Top:qqbar2ttbar = on` (no $p_\perp$ cut) for top.
   Hint 2: PYTHIA comes with a subset of FASTJET built-in, so you do not need to link to FASTJET. Appendix B.2 of the Worksheet describes the basic commands you need, and `examples/main05.cc` illustrates some of them. You are free to create three different instances of `SlowJet`, one for each algorithm.

3. a) Assume that the total cross section were to continue to grow like $21.7\, s^{0.08}$ (in units of mb, with s in units of GeV^2) and the elastic slope like $B_{\mathrm{el}} = 9.2 + 0.5\ln(s/4)$ (in units of GeV^{-2}). Then eventually the elastic cross section would exceed the total one — clearly unphysical. At about what evergy would that happen, and with what cross section? You can assume that $\rho \approx 0$.
   Hint: No analytical solution that I am aware of, so tabulate and interpolate.

4. Assume a detector coverage of $|\eta| < 5$ at 13 TeV LHC. Find the size of the largest gap from either edge of the detector:

$$\Delta\eta = \max\left(5 - \eta_{\mathrm{max}}, 5 + \eta_{\mathrm{min}}\right)$$

   where $\eta_{\mathrm{max/min}}$ is the particle with largest/smallest pseudorapidity (with sign!) inside the detector. Assume that particles need a $p_\perp > 0.2$ GeV to be detected, but include both charged and neutral ones. Compare the distribution and particularly the average value for nondiffractive and single diffractive. Also, how big a fraction of events do not have any particles at all in $|\eta| < 5$ (and should therefore not be histogrammed at all)?
   Hint: use `SoftQCD:nonDiffractive = on` and `SoftQCD:singleDiffractive = on`, respectively, for the two cases.