Exercises for Tutorial 4

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1 Top reconstruction

Top quarks and their decays are widely studied at the LHC. They are of intrinsic interest, as the heaviest particle in the Standard Model, they appear in Higgs physics studies, as decay products of new particles in beyond-standard-model searches, and also as a background for a range of processes. Top quarks decay to a b-quark and a W and the W may decay either to a lepton and a neutrino, or to a quark and anti-quark. In this tutorial, we consider the case where the W^+ decays to hadrons and the W^- decays to $\mu\bar{\nu}_\mu$. The example here (yet again called `main01`!) illustrates many of the issues of a practical analysis using jets, including questions such as the choice of jet radius, transverse-momentum cuts, etc.

If you cloned the tutorials previously, now do

```
git stash
git pull
```

and then go to the directory `tutorial-4/code`. Otherwise download a fresh zip file, unpack it and edit the `Makefile` in the above directory so that the path to Pythia points to where you built it previously.

Start by reading through the code to see if you can understand what it does. Some helper code is in the other files in the directory and for a first round you shouldn't need to look into those.

By default the code generates tree-level events: i.e. in Pythia, all radiation, hadronisation and multiple-interaction steps have been turned off.[1] How many jets do you expect to see at "Born" level (i.e. leading order, with no radiation)?

[1] But still Pythia still has to break up the proton to extract the partons that collide, and so events include a few proton-remnant particles.

Build and run the code and then generate a few plots:

```
make main01
./main01 -R 0.1 -ptmin 2.0 -ymax 5.0
gnuplot all-plots.gp
```

The options specify a small jet radius, and extremely loose (unrealistic) acceptance cuts. The gnuplot command should generate a PDF file `all-plots.pdf` (but you may need to edit the terminal and replace it e.g. with "pdf" or "postscript", depending on how gnuplot was build). The file has four pages, with the distribution of the number of jets, the number of b-tagged jets, and the distribution of candidate reconstructed hadronic W's and tops. Open the file to see what's in there (it has four pages).

1. By default 1000 events were generated. What fraction was well reconstructed, i.e. had the expected number of jets?

   Now try running with a normal jet radius and acceptance cuts

   ```
   make main01
   ./main01 -R 0.4 -ptmin 20.0 -ymax 2.5
   gnuplot all-plots.gp
   ```

   What fraction has the expected number of jets now? Scan the parameters individually to see how things change:

   (a) e.g. take $R = 0.1$, 0.4 and 1.0. Why does the number of jets go down as R increases?

   (b) Scan the $p_{t,\min}$ and $y_{\max}$ cuts and once again think about what you see.

2. Look at pages 3 and 4 to see the reconstructed mass plots. Why does the W mass distribution have some width? Why does the top-mass distribution have broad tails (you might want to look at the code again and think about how it is reconstructing the top-quark candidate).

3. Now edit the code and switch on all physical effects. What happens to the distributions?

   - What happens to the number of jets? Why?
   - What happens to the mass distributions? Why

4. With all physical effects in place vary the jet radius to see what value is optimal. You may also want turn individual effects on/off to understand how they impact the distributions.