Event Generator Physics: instructions for exercise

The purpose of this exercise is to study how different physics aspects affect event properties. As a simple example we assume that we want to study the properties of a Z' gauge boson, i.e. a heavier copy of the normal Z^0 one. The case of a 1 TeV mass has already been ruled out, but it offers a good way to illustrate the importance of parton showers, multiparton interactions and hadronization.

To begin, download the `mainZp.cc` file to your `pythia8307/examples` directory. Have a look at it, to check that you understand the overall flow of the code. The process used is $q\overline{q} \to \gamma^*/Z^0/Z'^0 \to q'\overline{q}'$, with full $\gamma^*/Z^0/Z'^0$ interference, but you can concentrate on the Z' peak region by restricting the generated mass window. The Z' identity code is 32, while 1–6 are the d, u, s, c, b and t quarks.

Compile and run the program with

```
make mainZp
./mainZp > mainZp.log &
```

Study `mainZp.log`, notably the two histograms at the end. Identify average number and spread, and note other properties, such as how often two jets are (not) found. Do you understand roughly what is going on?

If you have Python installed, you can also do

```
python plotZp.py
```

and open `figZp.pdf` for a nicer representation of the histograms, but without the statistics information explicit.

Once you are familiar with the basic setup, we can start to do variations around it, to study various effects. You will not have time for all of them, and do not need to do them in the order listed below. On the contrary, it would be useful if you branch out in different directions, using the various suggestions as inspiration. Reason whether results make sense, notably that effects go in the expected direction.

Bookkeep key results, at least by tabulating the average and spread of the two-jet mass for each run, and optionally by (re)naming the PDF files so that they are not overwritten. Consider the statistical significance of the difference between scenarios. You may want to increase the number of events generated, but for this exercise not so much that it seriously slows down the studies.

- Make use of further `pythia.readString("...");` commands to switch off one or more aspects of the full event generation, notably
  `PartonLevel:ISR = off` for no initial-state radiation,
  `PartonLevel:FSR = off` for no final-state radiation,
  `PartonLevel:MPI = off` for no multiparton interactions, and
  `HadronLevel:all = off` for no hadronization.
  How does each of these affect the average reconstructed mass?
- Instead switch all off as a starting point and then add back on one component at a time, and again quantify results.
- How would matters change for a different Z' mass? Use e.g. 200 GeV and 5 TeV as two extremes. Remember also to modify the Z' mass limits, the histogram upper

limit, and the `jetpTmin` scale in proportion (more or less).

- How would properties change if the jets were made narrower or broader, say `jetRadius` 0.4 or 1.0? Similarly if their minimal transverse momentum `jetpTmin` is modified? You could even switch from the anti-$k_\perp$ algorithm to the $k_\perp$ one, `jetPower = 1`, or the Cambridge/Aachen one, ditto `= 0`.
- Histogram the number of found jets. What would the effect be if all found jets are included in the invariant mass calculation for all events with at least two jets?
- The decay to top is not included above, since event topologies are much more complicated there. Nevertheless, do a run with $t = 6$ as the only `32:onIfAny` decay product.
- Study other event properties. For instance, you can plot the charged multiplicity of events, cf. `main01.cc`, and how it varies when different components are switched on/off. Or similarly the Z' $p_\perp$, but then for the last Z' copy in the event, after all effects have been added to it, cf. `main02.cc`.
- If you want to overlay curves from different conditions, it is feasible to have a big `for` loop, within which a new Pythia instance is created and destroyed with new settings each time. Preferably the booking of histograms would come before this big loop, and the plotting code after it.

Most of the variations above can be combined, e.g. to study a narrow/broad jet radius at a low Z' mass.

If you want to learn more about the theory behind your results:
G. Salam, "Towards Jetography",
Eur. Phys. J. C67 (2010) 637, `https://arxiv.org/abs/0906.1833`