Introduction to Phenomenology and Experiment of Particle Physics (PEPP)

Cycle 6

Event Properties

A jet is a jet is a jet

The main problem with comparing theoretical calculations involving QCD with experimental data from high energy colliders is that, while the calculations only involves quarks and gluons, the experiments only measure hadrons and leptons. The standard way of dealing with this is based on the realization that a highly energetic parton will give rise to a jet of hadrons in the same direction. Hence, by bunching together hadrons which are close in phase space and adding their momenta, it is possible to experimentally define a jet, which then can be compared to a theoretical calculation giving rise to an energetic quark or gluon.

The problem is how to define exactly what is meant by hadrons being *close in phase space*. There are two main strategies for doing this. One is to define a cone with some opening angle and try to find a direction in which the momentum of the particles in that cone is maximized. The other is an iterative procedure where a pair-wise measure is defined determining how *close* two particles are to each other. The algorithm is then to find the two particles which are closest and replace them with one pseudo particle carrying the sum of their momenta, and then to continue these clusterings until no (pseudo-) particle-pair are closer together than some cutoff. The remaining pseudo-particles are then defined as the jets.

In e^+e^- colliders, one typically uses clustering algorithms, while the cone algorithms (where the cone is conveniently defined in (η, ϕ)-space) are more popular at hadron colliders. However, currently there is a shift towards clustering algorithms also at hadron colliders, as the cone algorithms have some problems when applied to next-to-leading order calculations.

An alternative to these jet algorithms is to define some global variable which describes the general shape of an event. One such variable is called *thrust*, which in e^+e^- basically measures how *two-jet-like* an event is. Another is *sphericity*, which measures how spherically symmetric an event is. These quantities can then also be determined using theoretical calculations, as long as the quantities are collinear and infrared safe.

Literature

Most of this course is covered by

> R.K. Ellis, W.J. Stirling and B.R. Webber, *QCD and Collider Physics*, Cambridge University Press (1996).

and for this cycle the most relevant chapters are 6, 7 and 12. Additional input can be found in lecture notes from various summer schools, eg.

> T. Sjöstrand, *Monte Carlo Generators*, `hep-ph/0611247`.

A relevant comparison between different jet clustering algorithms can be found in

> L. Lönnblad, S. Moretti and T. Sjöstrand, *New and old jet clustering algorithms for electron positron events"*, `hep-ph/9804296`.

Goals

- Thrust and sphericity
- Multiplicity and rapidity distributions
- Jet clustering algorithms
- Jet cone algorithms

Exercises

1. Show that for three (massless) particles in their rest frame, the thrust axis is along the most energetic of the particles, and the thrust is given by its energy fraction $x = 2E_i/E_{tot}$.

2. Generate e^+e^- annihilation events at LEP energies using Pythia, and plot the thrust distribution. Also plot the thrust distribution with hadronization switched off to illustrate the size of the hadronization corrections.

3. Generate also e^+e^- annihilation events at lower energies, eg. down to 30 GeV, and study the hadronization corrections to the average thrust as a function of energy.

4. Show that sphericity is not a collinearly safe quantity.

5. Redo the analysis of hadronization effects above, using sphericity instead of thrust.

6. Using the *Durham* jet clustering algorithm on e^+e^- annihilation events at LEP energies, plot the number of three- and four-jet events as a function of the clustering cutoff. Do it both with and without hadronization.

7. Replace the Durham algorithm with the *Jade* algorithm and see if there is an effect on the hadronization corrections.