Introduction to Phenomenology and Experiment of Particle Physics (PEPP)

Cycle 4

Hadronic Collisions

Initial-state shower

Initial-state parton showers are intimately connected with the evolution of parton density functions (PDFs). In fact the purpose of them is to explicitly construct the splittings driving the PDF evolution. But while the evolution of PDFs typically starts with some parameterized input distribution at some low scale and applies DGLAP evolution to obtain the distribution at higher scales, the initial-state parton shower is typically constructed the other way around. After a sub-process has been generated at some high scale, the incoming partons are evolved *backwards* down to lower scales, explicitly constructing the splittings necessary.

To generate these splittings one uses Sudakov form factors just as in the final-state shower case. But while in the final-state, the Sudakov form factors correspond directly to no-emission probabilities, the backward evolution in the initial-state needs a combination of the standard Sudakov form factors and ratios of parton densities to get the no-emission probabilities. The way this is handled differs slightly between different programs.

One problem with the initial-state parton showers implemented according to the DGLAP formalism, is that all emissions are ordered in virtuality, or in transverse momentum. This means that for processes such as deeply inelastic ep-scattering at small $Q^2 \sim 10$ GeV^2 and small $x \sim 10^{-4}$, the probability of emitting high transverse momentum partons is suppressed, especially in the direction of the proton, although the available phase-space in principle is large. This is contrary to what is found eg. at HERA, where they have measured a large cross-section for so-called forward jets.

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 4 and 7. Additional input can be found in lecture notes from various summer schools, eg.

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

An overview and comparison between DGLAP and BFKL evolution can be found in

> G. Gustafson, *An Intuitive semiclassical picture of proton structure at small x.*, `hep-ph/0306108`.

Goals

- Evolution of parton density functions
- Initial-state parton showers
- Backward evolution
- Sudakov form factors and no-emission probabilities
- DGLAP vs. BFKL evolution at small x.

Exercises

1. Use the Durham web interface (`http://durpdg.dur.ac.uk/hepdata/pdf3.html`) to plot the u, d, $\bar{u}$ and gluon parton densities of some suitable PDF set. Use $Q^2 = 10^4 \mathrm{GeV}^2$ and plot down to $x = 10^{-4}$. The gluon may need to be scaled to fit into the same plot as the quarks.

2. Assuming a quark carries a fraction x_0 of the proton momentum at some scale Q_0^2, study how its average x is changed for $Q^2 > Q_0^2$.
   Hint: Use the Mellin transform and don't forget the +-prescription. You may use a fixed α_S.

3. Calculate the squared transverse momentum in the branching of a space-like parton into another space-like and a time-like one.
   Hint: Define z as the light-cone momentum fraction.

4. Describe the "Lund phase-space triangle".

   - Why can the allowed phase-space of any produced mass-less particle in a collision be approximated by the triangular region in the $(\log k_\perp^2, y)$ plane.
   - How would you draw lines with constant positive or negative light-cone momenta.
   - How would you best represent a massive particle in this kind of phase-space diagram.
   - A space-like incoming parton with some momentum fraction x and some transverse momentum $k_\perp$, does not have a well-defined rapidity. Suggest nevertheless a reasonable point for it in the phase-space triangle.