Exercises for Advanced Particle Physics - Winter term 2013/14

Exercise sheet No. VII

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The solutions have to be returned to mail box no. 1 in the foyer of the Gustav-Mie-House before **Monday, December 16th, 12:00h**.

Experimental signature of quarks and gluons

Quark and gluons are interacting via the strong interaction. The specific properties of the QCD make the direct observation of individual quarks or gluons impossible. Instead, a system of collimated hadrons - a jet - is observed. After considering the main argument which leads to the creation of jets, we propose to use Pythia to study a few properties of jets.

Exercise No. 1: Important features of QCD **(2 points)**

This exercise only requires to explain some aspects related to the hadronisation seen in the lecture. Since all the answers are in the lecture, the clarity of the explanation will mainly be evaluated.

1. Explain what is asymptotic freedom and confinement. What is the key element of the theory (not present in QED) which leads to this behavior?
2. By considering the reaction $e^+e^- \to q\bar{q}$, *explain* why individual quark (or gluon) are not observable and describe what should be observed in a detector (and explain why).

Exercise No. 2: Study of few jet properties **(8 points)**

The code to starts can be found in `http://rmadar.web.cern.ch/rmadar/Teaching/Pyhtia/QCD/`. The file `Generation_eeqqbar.cc` allows to generate $e^+e^- \to q\bar{q}$. The output file can be read with the two files `ProcessAnalysis.C` and `ProcessAnalysis.h`.

1. By generating $qg \to qg$ events, check the energy-momentum conservation between the partons (i.e. quark or gluon) and the resulting jets of hadrons. Hint: you can plot the 2D distribution of $\Delta R(q,i)$ VS $\Delta R(\bar{q},i)$[1], over stable particles i.
2. Plot the distribution of the number of particles per jet as well as the jet composition.
3. Plot the distribution of the electromagnetic/hadronic energy fraction as well as the fraction of neutral/charged energy. Where the electromagnetic energy comes from ? Describe the experimental signature of a jet.
4.
   - How is the energy distributed around the initial parton direction in the transverse plane η, ϕ. A plot is expected.
   - How does this distribution evolve with the energy of the initial parton? Interpret the result.
   - Compute the energy fraction f_x contained in a cone defined by $\Delta R < x$ and plot f_x versus x.
5. By simulating $qg \to qg$ with the file `GenerationQCDprocess_Hadro.cc`, plot the distribution requested in question 1. Comment the result and propose a qualitative explanation.

[1] We define $\Delta R_{ij} = \sqrt{(\eta_i - \eta_j)^2 + (\phi_i - \phi_j)^2}$, where η is the pseudo-rapidity defined in the lecture and ϕ is the azimuthal angle.

6. By simulating $e^+e^- \to b\bar{b}$, look at the particle content of jets coming from b-quark. What is the particle seen in those jets and not seen in jets from light quarks ? Explain. Plot the distribution of the number of particles and f_x for jets coming from the b-quark.

7. Produce summary plots where f_x and the number of particles for light quarks and b-quarks are overlaid.