Standard Model of Particle Physics

Lectures: Tilman Plehn, Ulrich Uwer
Exercises: James Barry, Christoph Englert, Dorival Gonçalves Netto, David López Val

Problem Sheet 12: Monte Carlo event generators

Notice the CHANGE OF LECTURE ROOM !!
The tutorial will take place in the **CIP Pool Albert-Ueberle-Str. 3-5** at the usual time.

Monte Carlo event generators can be thought as computer programs that produce particle physics events with the same probability as they occur in nature – this is to say, a sort of virtual collider. This last tutorial session of the Standard Model course is meant to be a very basic introduction to MadGraph/MadEvent, a widely used software which will allow you not only to simulate events, but also to generate the (leading-order) Feynman diagrams and corresponding matrix elements of a generic particle production process. In so doing, you will also revisit some of the important ideas on LHC phenomenology discussed in the theory lectures.

As a preparation for the tutorial, you are kindly requested to read the exercises below and to have a look at the suggested reading, in which you will find some introductory material to the computational tool we are going to use. You can find a handful of summarized presentations at the MadGraph/MadEvent wiki site,

`http://cp3wks05.fynu.ucl.ac.be/twiki/bin/view/Main/MadLectures`

A quick-start guide is available at

`http://cp3wks05.fynu.ucl.ac.be/Manual/Manual-March-2007.pdf`

On the theory side, Tilman's lecture notes on LHC Physics offer a comprehensive coverage of the topics we will address (cf. pages 35-44).

Problem 1: Higgs production cross sections at the LHC

Consider the following Higgs boson production channels at the LHC:

- Higgs boson production through gauge-boson fusion,

$$pp \to (VV^*) \to H^0 + 2\text{jets}\,, \quad V = W^\pm, Z^0$$

- Associated Higgs boson production,

$$pp \to H^0 + W^\pm/Z^0$$

1. Before you start to use the code: which partonic subchannels may contribute to each of the production mechanisms? Which one do you expect to be the dominant ? Which are the corresponding Feynman diagrams that describe the process at the leading-order ?

2. Use MadGraph to generate the whole set of Feynman diagrams. How close was your previous guess from the correct answer ? Think about what you missed at first sight and why ...

3. Using default input parameters, run MadEvent and compute the corresponding cross-sections for the LHC ($\sqrt{S} = 14$ TeV). Discuss your results; in particular, can you trace back the differences between the distinct partonic channels? How do the overall rates compare for each of the production mechanisms?

4. Together with the numerical prediction for the total cross-section, unweighted (parton-level) events are generated alongside and automatically represented as kinematic distributions. Compare the histograms you obtain for each of the channels and spell out the differences (e.g. how does the p_T distribution of the produced Higgs boson look like and why ?).

5. Analyse how the cross section predictions depend on: i) The value of the Higgs mass; ii) The choice of the renormalization and factorization scales.

Problem 2: Higgs boson signatures versus background

Hereafter we shall focus on the Higgs boson production through gauge-boson fusion channels, $pp \to (VV^*) \to H^0 + 2\text{jets}$, for a heavy Higgs boson, $M_H \sim 190$ GeV. In this setup, the preferred final-state signature corresponds to either 4 leptons or 2 leptons + missing energy, through the decay modes

$$H^0 \to W^+ W^- \to l^+ l^- \nu_l \bar{\nu}_l \,; \qquad H^0 \to Z^0 Z^0 \to l^+ l^- l^+ l^- .$$

Notice, nevertheless, that other processes exist giving rise to the very same final states, mainly the gauge boson pair production $pp \to (VV^*) \to VV + 2\text{jets}$. This is an example of **background** process, as it mimicks the trademark signature of the particle we are seeking for.

1. With the help of MadGraph, generate the whole set of Feynman diagrams that describe the Higgs boson production through $W^\pm$ fusion, plus its complete decay chain to a $W^\pm$-pair, and subsequently into leptons plus missing transverse energy. This is to say,

$$pp \to (W^{+*} W^{*-} \to H^0 + X \to W^+ W^- + X) \to 2l + \not{E}_T + 2\text{jets}.$$

   Do the same for the background process

$$pp \to (W^{+*} W^{*-} \to W^+ W^- + X) \to 2l + \not{E}_T + 2\text{jets}.$$

2. Using default input parameters and kinematic cuts, generate a sample of parton-level events for each process at the LHC ($\sqrt{S} = 14$ TeV). Compare the obtained cross sections and the the resulting distributions. What are the mentionable differences?

3. From the results you have obtained in the previous step: what kind of kinematic cuts might help to disentangle a potential Higgs boson signal from the background process ? Try them out and check whether they lead to an increase in the significance of the Higgs boson signal.

Additional information: put contact information here:
Christoph (`c.englert@thphys.uni-heidelberg.de`)
David (`d.lopez@thphys.uni-heidelberg.de`),
Dorival (`d.goncalves@thphys.uni-heidelberg.de`)
James (`james.barry@mpi-hd.mpg.de`)