Sherpa Tutorial

Part I

Introduction to Sherpa

1 About Sherpa

Sherpa is a full-featured event generator which puts special emphasis on an improved description of the perturbative stages of event generation, i.e. the hard-scattering process described by matrix elements and the parton shower stage with its resummation of soft and collinear enhancements.

One main ingredient to that aim is the generation of hard QCD emissions according to exact matrix elements, because the parton-shower approximation is not valid in that case. To run a parton-shower on top of such a matrix element which potentially already contains hard emissions the "CKKW merging" prescription is applied. Information about this formalism can be found in the Sherpa publication at arXiv:0811.4622 and in more detail at arXiv:0903.1219 and references therein. It has been extended to include next-to-leading order accuracy in the core process in arXiv:1009.1127. The related implementation of a "POWHEG style" algorithm is described in arXiv:1008.5399.

In addition to these perturbative event phases, Sherpa also has a cluster fragmentation module, hadron decays, and QED radiation resummed in the YFS approach.

2 Getting started

For this school Sherpa `v-1.3.1` has already been installed under `/opt/software/SHERPA-MC-1.3.1/`

To get all the needed run cards as well high-statistics results execute the command

```
$ wget http://physik2.uni-goettingen.de/~sschuma/SH_RunCards.tar.gz
```

unpack the downloaded file through

```
$ tar -zxf SH_RunCards.tar.gz
```

Two directories will be created, `SH_DY` and `SH_Jets`, corresponding to the two physics processes we consider in the following.

3 Run card

The way a particular Sherpa simulation runs is defined by several parameters, which can all be listed in a common file. The default name of this steering file is Run.dat, but other names can be used by specifying `RUNDATA=<run card>` on the Sherpa command line. The first step in running Sherpa is to adjust all parameters to the needs of the desired simulation. Instructions for properly constructing these files are given in the Sherpa manual (`http://projects.hepforge.org/sherpa/doc/SHERPA-MC-1.3.1.html`), but for now we will discuss a couple of the most important features.

In the "processes" section of the Run.dat file, the hard scattering processes that will be simulated are specified. The particles are identified by their PDG codes. There exist particle containers, which allow you to specify several processes with one line. For example, the particle container for jets, "93", includes all processes with $d, \bar{d}, u, \bar{u}, s, \bar{s}, c, \bar{c}, b, \bar{b}, G$ in this place. A list of particle codes and particle containers is displayed when Sherpa is run.

For all steps in these tutorials we have prepared run cards. To execute them run

```
$ Sherpa RUNDATA=<run card>
```

When you run Sherpa for a given setup the first time, it will integrate the cross sections. Depending on the hard processes specified in the run card this may take some time. The integration results get saved and re-used in later runs, for this the directory `Results` is created on run-time. If you want to use a different directory, you can define it in the run card by setting the parameter `RESULT_DIRECTORY`. **Warning:** When you change relevant parameters in the run card these integration results will have to be deleted such that they get re-generated accordingly.

The cross section of a specific Sherpa run is printed at the end of each run.

4 Plotting analysis outputs

To analyze events and display results we use the Rivet package, installed under

`/opt/software/Rivet-1.6.0/`

Documentation on Rivet you can find here

`http://projects.hepforge.org/rivet/`

Rivet's histogram output is written to `.aida` files. To plot and view the histograms, type

```
$ rivet-mkhtml -o <out_dir> file1.aida file2.aida ...
$ firefox <outdir>/index.html
```

The default output directory is `plots/`. Please make sure when running `rivet-mkhtml` output generated before doesn't get overwritten.

Part II

Physics analysis

We recommend to perform the physics analyses in teams of at least two students, one concentrating on generating events with Herwig++, one with Sherpa. At the end of the tutorial the results obtained with both codes shall be compared.

5 Z plus jets

We consider Z+jet production at the 7TeV LHC. We will be looking into various aspects of event generation, in particular the impact of higher-order corrections on physical observables. For monitoring results we employ the `MC_ZJETS` analysis of Rivet. The relevant run cards for this exercise you can find in `SH_DY`.

5.1 Tree-level matrix-element parton-shower merging

We want to study the impact of higher-order tree-level matrix-elements corrections on the parton-shower simulation. To this end we consider a plain parton-shower simulation first, `Run_MEPS_0j.dat`. Next we shall include exact matrix-element configurations with up to one, `Run_MEPS_01j.dat`, two, `Run_MEPS_012j.dat`, additional partons.

Generate 50k events for each sample and compare your results. Note, to save some time we have pre-integrated the cross sections for the sample with up to two additional jets, see `Results_MEPS_012j/`. Aida files for higher-statistics runs as well as runs up to three matrix-element partons can be found in the directory `Solutions`.

5.2 Event generation at the next-to-leading order

With `Run_POWHEG.dat` we provide a run card to generate Drell-Yan according to the `POWHEG` formalism, namely the core process being evaluated at NLO QCD. Make yourself familiar with the process setup and generate 10k events. Note, when generating events at the next-to-leading order prior to integration Sherpa generates process specific libraries that need to be compiled via, `$ makelibs`, before starting the generator again and actually integrating the cross section and generating events. Furthermore, for NLO events at present Sherpa allows for weighted events only.

For completeness we provide you with a run card corresponding to a `MENLOPS` setup, cf. `Run_MENLOPS.dat`. However, its execution requires more time than we have today. Nevertheless, in `Solutions/` you can find corresponding aida files that we have generated using this run card.

5.3 Tasks

- Compare the results obtained for the `POWHEG` run with those from tree-level merging. Determine the K-factor $\sigma_{\text{tot}}^{\text{NLO}}/\sigma_{\text{tot}}^{\text{LO}}$.
- How does the `MENLOPS` sample compare to `POWHEG` and tree-level merging with up to tree partons?
- Test the impact of switching on the underlying event simulation in the tree-level merging simulation, cf. `Run_MEPS_UE_0j.dat` & `Run_MEPS_UE_01j.dat`. Which observables are most/least sensitive to the underlying event?

6 Jet shapes

In this exercise we want to compare generator predictions for jet-shape observables against a recent measurement from Atlas presented arXiv:1101.0070 [hep-ex]. Both, a differential jet-shape,

$$\rho(r) = \frac{1}{\Delta r}\frac{1}{N_{\text{jet}}}\sum_{\text{jets}}\frac{p_T(r-\Delta r/2, r+\Delta r/2)}{p_T(0,R)}\,, \quad \Delta r/2 \le r \le R-\Delta r/2\,, \text{ here } \Delta r = 0.1,$$

and an integrated variable,

$$\Psi(r) = \frac{1}{N_{\text{jet}}}\sum_{\text{jets}}\frac{p_T(0,r)}{p_T(0,R)}\,, \quad 0 \le r \le R\,,$$

are considered. The input jets are clustered according to the anti-k_T algorithm with distance parameter $R = 0.6$.
With the input files

`Run_PS_HADoff_UEoff.dat` `Run_PS_HADon_UEoff.dat` `Run_PS_HADn_UEon.dat`

provided in the `SH_Jets/` directory you can simulate inclusive dijet production at the LHC and compare to the data from ATLAS. We start with only the parton shower switched on, then we add hadronization and finally we also enable underlying events. Generate 10k events for each sample here, aida files from runs with higher statistics can be found in the directory `Solutions/`.

6.1 Tasks

- How do $\rho(r)$ and $\Psi(r)$ behave at leading-order in QCD?
- Study the impact of hadronization and underlying event on ρ and Ψ. Interpret your results.
- Are high-p_T jets wider or narrower than lower-p_T ones?

That's it!

Thanks for trying Sherpa! If you have any questions later on, please email us at `info@sherpa-mc.de` or have a look at `http://www.sherpa-mc.de`, where you can find online documentation, sample results and many references.