Collider exercises - preliminary setup

10th IDPASC School

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Phenomenological analyses in high energy physics require two main steps:

1. the possibility to simulate collision events with a Monte Carlo generator, and interface such events with codes which deal with parton showers, hadronisation and the simulation of the LHC detectors;

2. codes which analyse the simulations to extract the relevant physical information for theorists to understand how to constrain models or find out the best ways to test them, and for experimentalists to optimise the strategies to achieve the best sensitivity to the observables under consideration.

The exercise is meant to drive you through such steps for a simple analysis related to dark matter phenomenology, using state-of-the-art software, *i.e.* the software actually used to produce phenomenological and experimental papers.

The main **public** software we would like to use is developed for Linux systems and, while it works perfectly on MacOS, it had problems in the past with Windows. The purpose of this preliminary document is to understand if you have any problem in installing and using it. Such software is:

- MadGraph5_aMC@NLO `https://launchpad.net/mg5amcnlo`
- Pythia 8 `https://pythia.org/`
- MadAnalysis 5 `https://launchpad.net/madanalysis5`. The suggested version is v1.9, which includes files for old compilers and can be found at
  `https://bazaar.launchpad.net/~ma5dev/madanalysis5/v1.9_beta/tarball`
  (if the link does not work, the corresponding tarball is in the indico page)

Even if **not necessary for the exercise**, for those interested in adding further layers to the study and make it closer to what is actually done in a research analysis, the following software are also suggested:

- Root `https://root.cern.ch/`
- Delphes 3 `https://cp3.irmp.ucl.ac.be/projects/delphes`

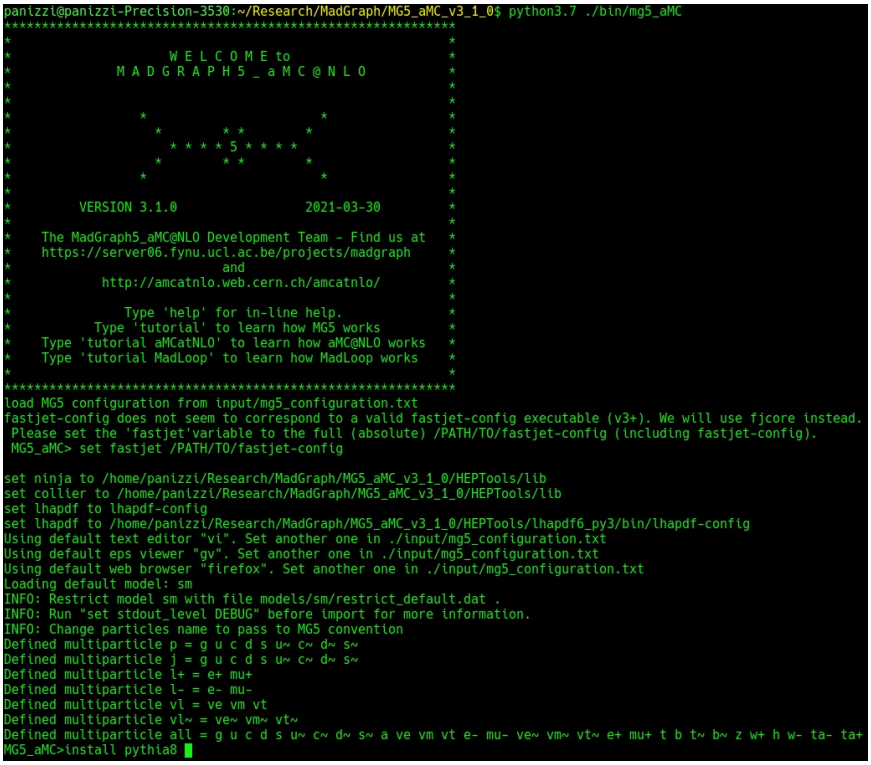
It is possible to obtain and install all these pieces of software except Root within the MadGraph5_aMC@NLO framework, by downloading it at and uncompressing the tarball in a directory of your choice.[1]

[1] **Only for Windows users.** To install MadGraph on Windows there are different ways. These are, from less invasive to most invasive (roughly):

- setup linux on a virtual machine
- using cygwin (`https://www.cygwin.com/`)
- install Ubuntu via Wubi (`https://help.ubuntu.com/community/Wubi`)
- boot through USB key (you won't be able to save data on your system, will have to rely on some external drive)
- setting a dual boot on your machine.

In any case, try to google the best solution for you. There are many pages which describe how to setup a linux environment on Windows, also with the possibility to uninstall everything related to linux afterwards without affecting your previous settings. We let you browse the best solution, without suggesting a specific one.

To start MadGraph5_aMC@NLO and install Pythia 8 type the following commands in your terminal:



Notice that MadGraph5_aMC@NLO works with Python 2.7 or Python 3.7. If your system has older versions, an error message appears if you try to simply execute the `mg5_aMC` command (as it is the case in the example below):

```
panizzi@panizzi-Precision-3530:~/Research/MadGraph/MG5_aMC_v3_1_0$ ./bin/mg5_aMC
MadGraph5_aMC@NLO works only with python 2.7 or python 3.7 (and later).
  You are currently using Python 3.6. So please upgrade your version of Python.  If you have python2.7 installed you need to run the code as
      python27 ./bin/mg5_aMC
```

After Pythia 8 has been installed (it will take a few minutes) you can repeat the same procedure for installing MadAnalysis 5 or any other software that might be useful, which appears by pressing the Tab key twice after typing `install` in the MadGraph5_aMC@NLO environment.

A simple test

You can run a version of this test by typing `tutorial` in the `mg5_aMC` environment. This contains step-by-step instructions and describes many more features not covered here.

To check if MadGraph5_aMC@NLO runs properly we can try to simulate a process of top pair production at the LHC, by typing the following command and, if everything worked, getting the following output:

```
MG5_aMC>generate p p > t t~
INFO: Checking for minimal orders which gives processes.
INFO: Please specify coupling orders to bypass this step.
INFO: Trying coupling order WEIGHTED<=2: WEIGTHED IS QCD+2*QED
INFO: Trying process: g g > t t~ WEIGHTED<=2 @1
INFO: Process has 3 diagrams
INFO: Trying process: u u~ > t t~ WEIGHTED<=2 @1
INFO: Process has 1 diagrams
INFO: Trying process: u c~ > t t~ WEIGHTED<=2 @1
INFO: Trying process: c u~ > t t~ WEIGHTED<=2 @1
INFO: Trying process: c c~ > t t~ WEIGHTED<=2 @1
INFO: Process has 1 diagrams
INFO: Trying process: d d~ > t t~ WEIGHTED<=2 @1
INFO: Process has 1 diagrams
INFO: Trying process: d s~ > t t~ WEIGHTED<=2 @1
INFO: Trying process: s d~ > t t~ WEIGHTED<=2 @1
INFO: Trying process: s s~ > t t~ WEIGHTED<=2 @1
INFO: Process has 1 diagrams
INFO: Process u~ u > t t~ added to mirror process u u~ > t t~
INFO: Process c~ c > t t~ added to mirror process c c~ > t t~
INFO: Process d~ d > t t~ added to mirror process d d~ > t t~
INFO: Process s~ s > t t~ added to mirror process s s~ > t t~
5 processes with 7 diagrams generated in 0.017 s
Total: 5 processes with 7 diagrams
MG5_aMC>
```

You can display the Feynman diagrams associated with the process by typing `display diagrams` after the generation of the topologies.

Finally, to export the process into a working directory type the following and see if you get the subsequent output (disregard the yellow lines, they won't appear for you unless you install the MadSTR and MadDM plugins)

```
MG5_aMC>output ttbartest
Plugin PLUGIN.MadSTR has marked as NOT being validated with this version.
It has been validated for the last time with version: 2.5.0
error detected in plugin: maddm.
No module named 'maddm_interface'
INFO: initialize a new directory: ttbartest
INFO: remove old information in ttbartest
INFO: Organizing processes into subprocess groups
INFO: Generating Helas calls for process: g g > t t~ WEIGHTED<=2 @1
INFO: Processing color information for process: g g > t t~ @1
INFO: Generating Helas calls for process: u u~ > t t~ WEIGHTED<=2 @1
INFO: Processing color information for process: u u~ > t t~ @1
INFO: Combined process c c~ > t t~ WEIGHTED<=2 @1 with process u u~ > t t~ WEIGHTED<=2 @1
INFO: Combined process d d~ > t t~ WEIGHTED<=2 @1 with process u u~ > t t~ WEIGHTED<=2 @1
INFO: Combined process s s~ > t t~ WEIGHTED<=2 @1 with process u u~ > t t~ WEIGHTED<=2 @1
INFO: Creating files in directory P1_gg_ttx
INFO: Some T-channel width have been set to zero [new since 2.8.0]
 if you want to keep this width please set "zerowidth_tchannel" to False
INFO: Generating Feynman diagrams for Process: g g > t t~ WEIGHTED<=2 @1
INFO: Finding symmetric diagrams for subprocess group gg_ttx
INFO: Creating files in directory P1_qq_ttx
INFO: Generating Feynman diagrams for Process: u u~ > t t~ WEIGHTED<=2 @1
INFO: Finding symmetric diagrams for subprocess group qq_ttx
Generated helas calls for 2 subprocesses (4 diagrams) in 0.007 s
Wrote files for 16 helas calls in 0.057 s
ALOHA: aloha starts to compute helicity amplitudes
ALOHA: aloha creates 2 routines in  0.311 s
save configuration file to /home/panizzi/Research/MadGraph/MG5_aMC_v3_1_0/ttbartest/Cards/me5_configuration.txt
INFO: Use Fortran compiler gfortran
INFO: Use c++ compiler g++
INFO: Generate jpeg diagrams
INFO: Generate web pages
INFO: Generating MadAnalysis5 default cards tailored to this process
Output to directory /home/panizzi/Research/MadGraph/MG5_aMC_v3_1_0/ttbartest done.
Type "launch" to generate events from this process, or see
/home/panizzi/Research/MadGraph/MG5_aMC_v3_1_0/ttbartest/README
Run "open index.html" to see more information about this process.
MG5_aMC>
```

Now all the necessary files to perform the analysis are in the folder called `ttbartest`, so we can type `exit` and navigate to it. Once inside the folder we can enter the `madevent` environment and perform the simulation.

```
panizzi@panizzi-Precision-3530:~/Research/MadGraph/MG5_aMC_v3_1_0/ttbartest$ python3.7 ./bin/madevent
launch in debug mode
************************************************************
*                                                          *
*                    W E L C O M E to                      *
*           M A D G R A P H 5 _ a M C @ N L O              *
*                    M A D E V E N T                       *
*                                                          *
*                *                       *                 *
*                  *        * *        *                   *
*                    * * * * 5 * * * *                     *
*                  *        * *        *                   *
*                *                       *                 *
*                                                          *
*         VERSION 3.1.0                20xx-xx-xx          *
*                                                          *
*    The MadGraph5_aMC@NLO Development Team - Find us at   *
*    https://server06.fynu.ucl.ac.be/projects/madgraph     *
*                                                          *
*               Type 'help' for in-line help.              *
*                                                          *
************************************************************
INFO: load configuration from /home/panizzi/Research/MadGraph/MG5_aMC_v3_1_0/ttbartest/Cards/me5_configuration.txt
INFO: load configuration from /home/panizzi/Research/MadGraph/MG5_aMC_v3_1_0/input/mg5_configuration.txt
INFO: load configuration from /home/panizzi/Research/MadGraph/MG5_aMC_v3_1_0/ttbartest/Cards/me5_configuration.txt
Using default text editor "vi". Set another one in ./input/mg5_configuration.txt
Using default eps viewer "gv". Set another one in ./input/mg5_configuration.txt
Using default web browser "firefox". Set another one in ./input/mg5_configuration.txt
ttbartest>
```

In this preliminary setup we are not interested in understanding how to interpret the results, but only in checking if everything runs and does not produce error messages.

To launch the simulation including Pythia 8 and MadAnalysis 5 type the `launch` command, followed by a name of your choice (this will be the name of the simulation), and the following output appears (depending on the software you installed you might have some options not enabled):

```
ttbartest>launch test
The following switches determine which programs are run:
/================== Description ==================|================== values ==================|===== other options ======\
| 1. Choose the shower/hadronization program       |        shower = OFF                        |     Pythia8              |
| 2. Choose the detector simulation program        |      detector = OFF                        |     Delphes              |
| 3. Choose an analysis package (plot/convert)     |      analysis = MadAnalysis4               |     MadAnalysis5|OFF     |
| 4. Decay onshell particles                       |       madspin = OFF                        |     ON|onshell|full      |
| 5. Add weights to events for new hypp.           |      reweight = OFF                        |     ON                   |
\=================================================================================================================================/
Either type the switch number (1 to 5) to change its setting,
Set any switch explicitly (e.g. type 'shower=Pythia8' at the prompt)
Type 'help' for the list of all valid option
Type '0', 'auto', 'done' or just press enter when you are done.[60s to answer]
>
```

You can then follow the instructions given by `madevent` to switch on Pythia 8 and MadAnalysis 5, such that you get the following:

```
/================== Description ==================|================== values ==================|===== other options ======\
| 1. Choose the shower/hadronization program       |        shower = Pythia8                    |     OFF                  |
| 2. Choose the detector simulation program        |      detector = OFF                        |     Delphes              |
| 3. Choose an analysis package (plot/convert)     |      analysis = MadAnalysis5               |     OFF|MadAnalysis4     |
| 4. Decay onshell particles                       |       madspin = OFF                        |     ON|onshell|full      |
| 5. Add weights to events for new hypp.           |      reweight = OFF                        |     ON                   |
\=================================================================================================================================/
```

The next set step is to set the simulation parameters: for this test we simply set a very small number of events (10) for speeding up the simulation, and this is done by typing `set nevents 10` as in the following:

```
Do you want to edit a card (press enter to bypass editing)?
/-----------------------------------------------------------\
|  1. param               : param_card.dat                  |
|  2. run                 : run_card.dat                    |
|  3. pythia8             : pythia8_card.dat                |
|  4. madanalysis5_parton : madanalysis5_parton_card.dat    |
|  5. madanalysis5_hadron : madanalysis5_hadron_card.dat    |
\-----------------------------------------------------------/
 you can also
   - enter the path to a valid card or banner.
   - use the 'set' command to modify a parameter directly.
     The set option works only for param_card and run_card.
     Type 'help set' for more information on this command.
   - call an external program (ASperGE/MadWidth/...).
     Type 'help' for the list of available command
 [0, done, 1, param, 2, run, 3, pythia8, 4, enter path, ... ][90s to answer]
>set nevents 10
```

If you type enter, the simulation starts and will produce some output. You should get a terminal output similar to the one below:

```
INFO: #*********************************************************************
#
# original cross-section: 505.4899999999999
#     scale variation: +29.7% -21.1%
#     central scheme variation: +3.3e-07% -23.6%
# PDF variation: +5.64% -5.64%
#
# dynamical scheme # 1 : 491.185 +30.5% -21.6% # \sum ET
# dynamical scheme # 2 : 398.952 +26.7% -19.7% # \sum\sqrt{m^2+pt^2}
# dynamical scheme # 3 : 505.49 +29.7% -21.1% # 0.5 \sum\sqrt{m^2+pt^2}
# dynamical scheme # 4 : 386.258 +26.4% -19.5% # \sqrt{\hat s}
#*********************************************************************

INFO: End of systematics computation
store_events
INFO: Storing parton level results
INFO: End Parton
reweight -from_cards
decay_events -from_cards
INFO: Running MadAnalysis5 [arXiv:1206.1599]
INFO: Parton input file considered:
INFO:   --> /home/panizzi/Research/MadGraph/MG5_aMC_v3_1_0/tttt/Events/test/unweighted_events.lhe.gz
INFO: MadAnalysis5 now running the 'analysis1' analysis...
INFO: Follow Madanalysis5 run with the following command in a separate terminal:
INFO:   tail -f /home/panizzi/Research/MadGraph/MG5_aMC_v3_1_0/tttt/Events/test/tag_1_MA5_analysis1.log
INFO: MadAnalysis5 successfully completed the analysis 'analysis1'. Reported results are placed in:
INFO:   --> /home/panizzi/Research/MadGraph/MG5_aMC_v3_1_0/tttt/Events/test/tag_1_MA5_parton_analysis_analysis1.pdf
INFO: Finished MA5 analyses.
INFO: Running Pythia8 [arXiv:1410.3012]
Splitting .lhe event file for PY8 parallelization...
Submitting Pythia8 jobs...
Pythia8 shower jobs: 1 Idle, 0 Running, 0 Done [0 second]
Pythia8 shower jobs: 0 Idle, 0 Running, 1 Done [3 seconds]
Merging results from the split PY8 runs...
INFO: Pythia8 shower finished after 3 seconds.
INFO: No delphes_card detected, so not run Delphes
  === Results Summary for run: test tag: tag_1 ===

     Cross-section :   505.5 +- 4.213 pb
     Nb of events :  10

INFO: storing files of previous run
INFO: Storing Pythia8 files of previous run
INFO: Done
INFO: Running MadAnalysis5 [arXiv:1206.1599]
INFO: Hadron input files considered:
INFO:   --> /home/panizzi/Research/MadGraph/MG5_aMC_v3_1_0/tttt/Events/test/tag_1_pythia8_events.hepmc.gz
INFO: MadAnalysis5 now running the reconstruction 'BasicReco'...
INFO: Follow Madanalysis5 run with the following command in a separate terminal:
INFO:   tail -f /home/panizzi/Research/MadGraph/MG5_aMC_v3_1_0/tttt/Events/test/tag_1_MA5__reco_BasicReco.log
INFO: MadAnalysis5 successfully completed the reconstruction 'BasicReco'. Links to the reconstructed event files are:
INFO:   --> /home/panizzi/Research/MadGraph/MG5_aMC_v3_1_0/tttt/Events/test/tag_1_pythia8_BasicReco.lhe.gz
INFO: MadAnalysis5 now running the 'analysis2_BasicReco' analysis...
INFO: Follow Madanalysis5 run with the following command in a separate terminal:
INFO:   tail -f /home/panizzi/Research/MadGraph/MG5_aMC_v3_1_0/tttt/Events/test/tag_1_MA5_analysis2_BasicReco.log
INFO: MadAnalysis5 successfully completed the analysis 'analysis2_BasicReco'. Reported results are placed in:
INFO:   --> /home/panizzi/Research/MadGraph/MG5_aMC_v3_1_0/tttt/Events/test/tag_1_MA5_hadron_analysis_analysis2_BasicReco.pdf
INFO: Finished MA5 analyses.
```

The numbers you will obtain might be different from those in the screenshot because this is a Monte Carlo simulation, which is based on a random scan of the phase space: with such a small number of events, the statistics is extremely limited and the uncertainties are very large. Numerical discrepancies are therefore very well possible.

If you get to this point without error messages you are all set for the exercise.

Please let us know if you have any error or if you have any problem to perform the test above, as otherwise we will assume that everything is ok and proceed.

The final pre-requisite for the exercise is to download the UFO model corresponding to t-channel dark matter scenarios and decompress the tarball in the `models` folder inside MadGraph5_aMC@NLO (create a directory inside `models` and uncompress the files there). The model files can be found at
`http://feynrules.irmp.ucl.ac.be/raw-attachment/wiki/DMsimpt/dmsimpt_v1.2.ufo.tar.gz`