MadGraph5_aMC@NLO tutorials@UniMi

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NLO exercise
$t\bar{t}$ production at NLO

Part I

- Learn the syntax:
  - > `tutorial aMCatNLO`
- Generate the code for $t\bar{t}$ production at NLO
- Compute the LO and NLO cross-section (run at fixed order)
- Select the analysis `analysis_HwU_pp_ttx.o` in the `FO_analyse_card` to generate histograms (need `GnuPlot` installed)
- In the NLO histograms, which of these variables are described at the NLO? $p_T(t)$, $p_T(t\bar{t})$, $y(t)$ $M(t\bar{t})$, $\Delta\phi(t\bar{t})$
- What are the histograms with `muR=...` `muF=...` for?

NLO exercise Solution

Part I

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ted:
                                                order=NLO
g):   fixed_order=OFF
                                              shower=ON
                                            madspin=OFF
ult setting,
 prompt)
 Type '0', 'auto', 'done' or just press enter when you are done.
 [0, 1, 2, 3, 4, auto, done, order=LO, order=NLO, ... ][60s to answer]
> fixed_order=ON
> order=LO (for LO run)
```

```
INFO:
      Final results and run summary:
      Process p p > t t~ [QCD]
      Run at p-p collider (6500 + 6500 GeV)
      Total cross-section:      6.871e+02 +- 5.9e+00 pb
      Ren. and fac. scale uncertainty: +9.7% -11.7%

INFO: The results of this run and the HwU and GnuPlot
files with the plots have been saved in /Users/marcozaro/
Physics/MadGraph/2.2.3new/my_tt_nlo_qcd/Events/run_01

INFO:
      Final results and run summary:
      Process p p > t t~ [QCD]
      Run at p-p collider (6500 + 6500 GeV)
      Total cross-section:      4.622e+02 +- 2.2e+00 pb
      Ren. and fac. scale uncertainty: +29.8% -22.3%

INFO: The results of this run and the HwU and GnuPlot
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Physics/MadGraph/2.2.3new/my_tt_nlo_qcd/Events/run_02_LO
```

Part I

- Select

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```
##################################################################
#
# This file contains the settings for analyses to be linked to aMC@NLO
# fixed order runs. Analyse files are meant to be put (or linked)
# inside <PROCDIR>/FixedOrderAnalysis/ (<PROCDIR> is the name of the
# exported process directory). See the
# <PROCDIR>/FixedOrderAnalysis/analysis_template.f file for details on
# how to write your own analysis.
#
##################################################################
#
# Analysis format. Can either be 'topdrawer', 'root', 'HwU' or 'none'.
# When choosing HwU, it comes with a GnuPlot wrapper. When choosing
# topdrawer, the histogramming package 'dbook.f' is included in the
# code, while when choosing root the 'rbook_fe8.f' and 'rbook_be8.cc'
# are included. If 'none' is chosen, all the other entries below have
# to be set empty.
FO_ANALYSIS_FORMAT = HwU
#
# Needed extra-libraries (FastJet is already linked):
FO_EXTRALIBS =
#
# (Absolute) path to the extra libraries. Directory names should be
# separated by white spaces.
FO_EXTRAPATHS =
#
# (Absolute) path to the dirs containing header files needed by the
# libraries (e.g. C++ header files):
FO_INCLUDEPATHS =
#
# User's analysis (to be put in the <PROCDIR>/FixedOrderAnalysis/
# directory). Please use .o as extension and white spaces to separate
# files.
FO_ANALYSE = analysis_HwU_pp_ttx.o
#
#
## When linking with root, the following settings are a working
## example on lxplus (CERN). When using this, comment out the lines
## above and replace <PATH_TO_ROOT> with the physical path to root,
## e.g. /afs/cern.ch/sw/lcg/app/releases/ROOT/5.34.11/x86_64-slc6-gcc46-dbg/root/
#FO_ANALYSIS_FORMAT = root
#FO_EXTRALIBS = Core Cint Hist Matrix MathCore RIO dl Thread
#FO_EXTRAPATHS = <PATH_TO_ROOT>/lib
#FO_INCLUDEPATHS = <PATH_TO_ROOT>/include
#FO_ANALYSE = analysis_root_template.o
```

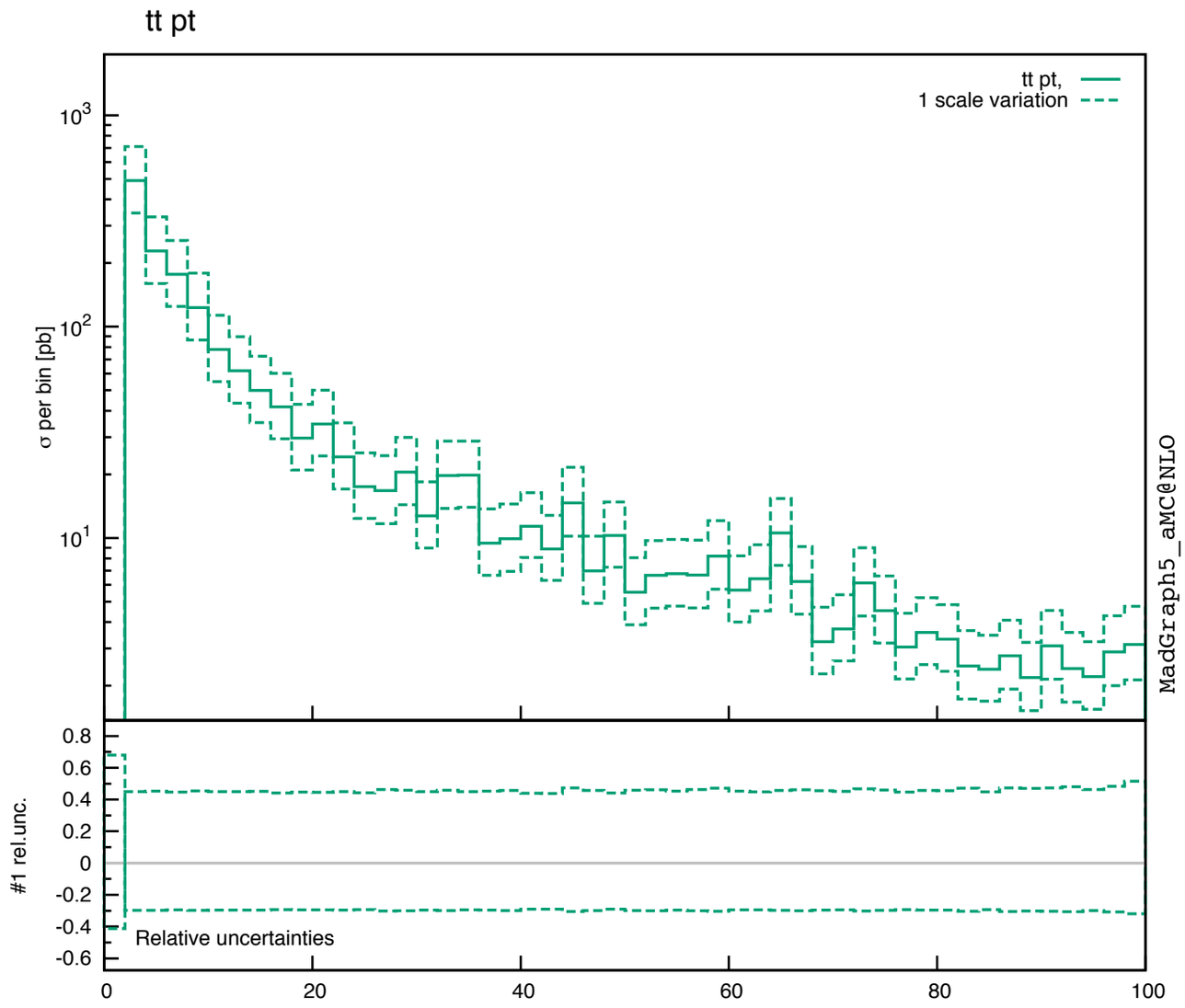
NLO exercise: solution

- The HwU (Histogram with Uncertainties) format

```
 ##& xmin & xmax & central value & dy & delta_mu_min @aux & delta_mu_max @aux & muR=1.00 muF=1.00 & muR=1.00 muF=2.00 &
muR=1.00 muF=0.50 & muR=2.00 muF=1.00 & muR=2.00 muF=2.00 & muR=2.00 muF=0.50 & muR=0.50 muF=1.00 & muR=0.50 muF=2.00 &
muR=0.50 muF=0.50

<histogram> 50 "tt pt |X_AXIS@LIN |Y_AXIS@LOG"
  +0.0000000e+00   +2.0000000e+00   -1.0242367e+03   +2.5047252e+01  -1.7206530e+03   -6.0160203e+02   -1.0242367e+03
-9.0715087e+02   -1.1432407e+03   -6.8421704e+02   -6.0160203e+02   -7.6882229e+02   -1.5496422e+03   -1.3802509e+03
-1.7206530e+03
  +2.0000000e+00   +4.0000000e+00   +4.9088904e+02   +2.0297264e+01  +3.4493531e+02   +7.1188196e+02   +4.9088904e+02
+4.5019210e+02   +5.3086979e+02   +3.7613186e+02   +3.4493531e+02   +4.0679297e+02   +6.5832080e+02   +6.0377117e+02
+7.1188196e+02
  +4.0000000e+00   +6.0000000e+00   +2.2787754e+02   +2.3122314e+01  +1.5999659e+02   +3.3086836e+02   +2.2787754e+02
+2.0857157e+02   +2.4714205e+02   +1.7482611e+02   +1.5999659e+02   +1.8963760e+02   +3.0513912e+02   +2.7932554e+02
+3.3086836e+02
  +6.0000000e+00   +8.0000000e+00   +1.7671803e+02   +9.5392210e+00  +1.2453269e+02   +2.5575724e+02   +1.7671803e+02
+1.6227348e+02   +1.9111959e+02   +1.3562893e+02   +1.2453269e+02   +1.4669918e+02   +2.3651862e+02   +2.1720764e+02
+2.5575724e+02
  +8.0000000e+00   +1.0000000e+01   +1.2311654e+02   +7.1903869e+00  +8.6399100e+01   +1.7898773e+02   +1.2311654e+02
+1.1261446e+02   +1.3369767e+02   +9.4461506e+01   +8.6399100e+01   +1.0258866e+02   +1.6483914e+02   +1.5078780e+02
+1.7898773e+02
  +1.0000000e+01   +1.2000000e+01   +7.8022445e+01   +1.0748137e+01  +5.4873577e+01   +1.1315020e+02   +7.8022445e+01
+7.1570742e+01   +8.4452355e+01   +5.9823787e+01   +5.4873577e+01   +6.4760050e+01   +1.0454718e+02   +9.5909144e+01
+1.1315020e+02
  +1.2000000e+01   +1.4000000e+01   +6.1770611e+01   +3.2903213e+00  +4.3437593e+01   +8.9537046e+01   +6.1770611e+01
```

NLO exercise
Solution



NLO exercise
Solution

Part I

- In the NLO histograms, which of these variables are described at the NLO? $p_T(t)$, $p_T(t\bar{t})$, $y(t)$ $M(t\bar{t})$, $\Delta\phi(t\bar{t})$
  - Some of these variables are trivial at LO, because of $2\to2$ kinematics
    - t and $\bar{t}$ are always back to back:

$$d\sigma/d\Delta\Phi(t\bar{t}) = \delta(\Delta\Phi - \pi)$$
$$d\sigma/dp_T(t\bar{t}) = \delta(p_T - 0)$$

- $p_T(t\bar{t})$ and $\Delta\phi(t\bar{t})$ are non-trivial if the cross-section is at least at NLO: they are effectively described with LO accuracy
- The other variables are described at NLO

NLO exercise
Solution

Part I

- What are the histograms with `muR=...  muF=...` for?
  - QCD master formula

$$\sigma(pp \to t\bar{t}) = \sum_{ab} \int dx_1 dx_2 f_a(x_1, \mu_F) f_b(x_2, \mu_F) \times \hat{\sigma}(ab \to t\bar{t})$$

    or better

$$\sigma(pp \to t\bar{t}) = \sum_{ab} \int dx_1 dx_2 f_a(x_1, \mu_F) f_b(x_2, \mu_F) \times \hat{\sigma}(ab \to t\bar{t}; \mu_F, \mu_R, \alpha_S(\mu_R))$$

  - What are $\mu_{F/R}$?
    - They are arbitrary scales needed to renormalise the strong coupling and to reabsorb initial state IR-divergences in PDFs, chosen to be of the order of the hard scattering scales (sum of masses, p_T, …)
    - The all-order cross-section is independent of the choice of $\mu_{F/R}$
    - At N^{k}LO, the dependence is of N^{k+1}LO

Scale uncertainties

- Look at the LO and NLO cross-section we have just computed
  - Values with different scales are computed on the fly and the envelope is taken
- Typically LO has larger
- To have scale uncertain
  histogram per scale cho
- The same is possible fo

```
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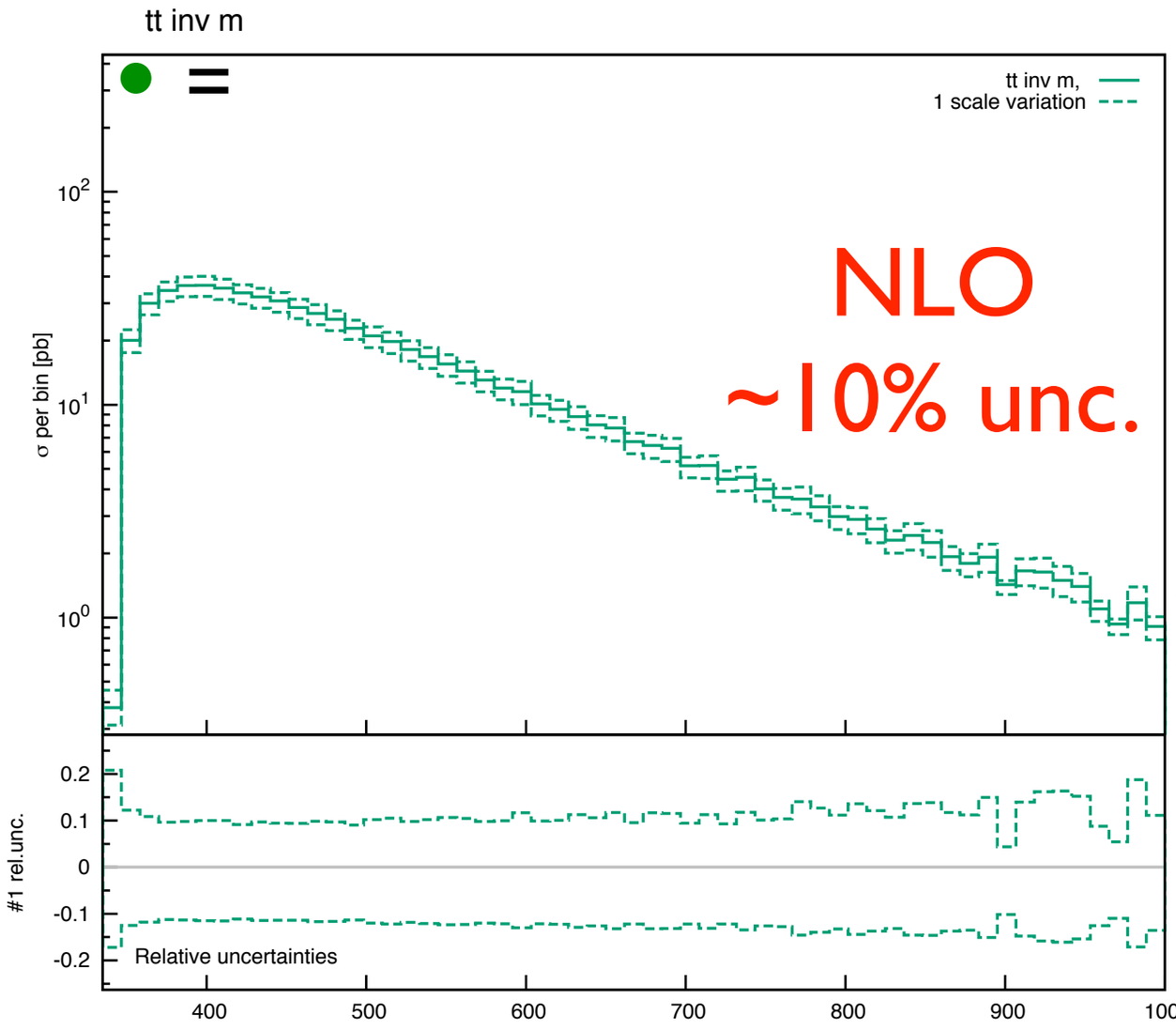
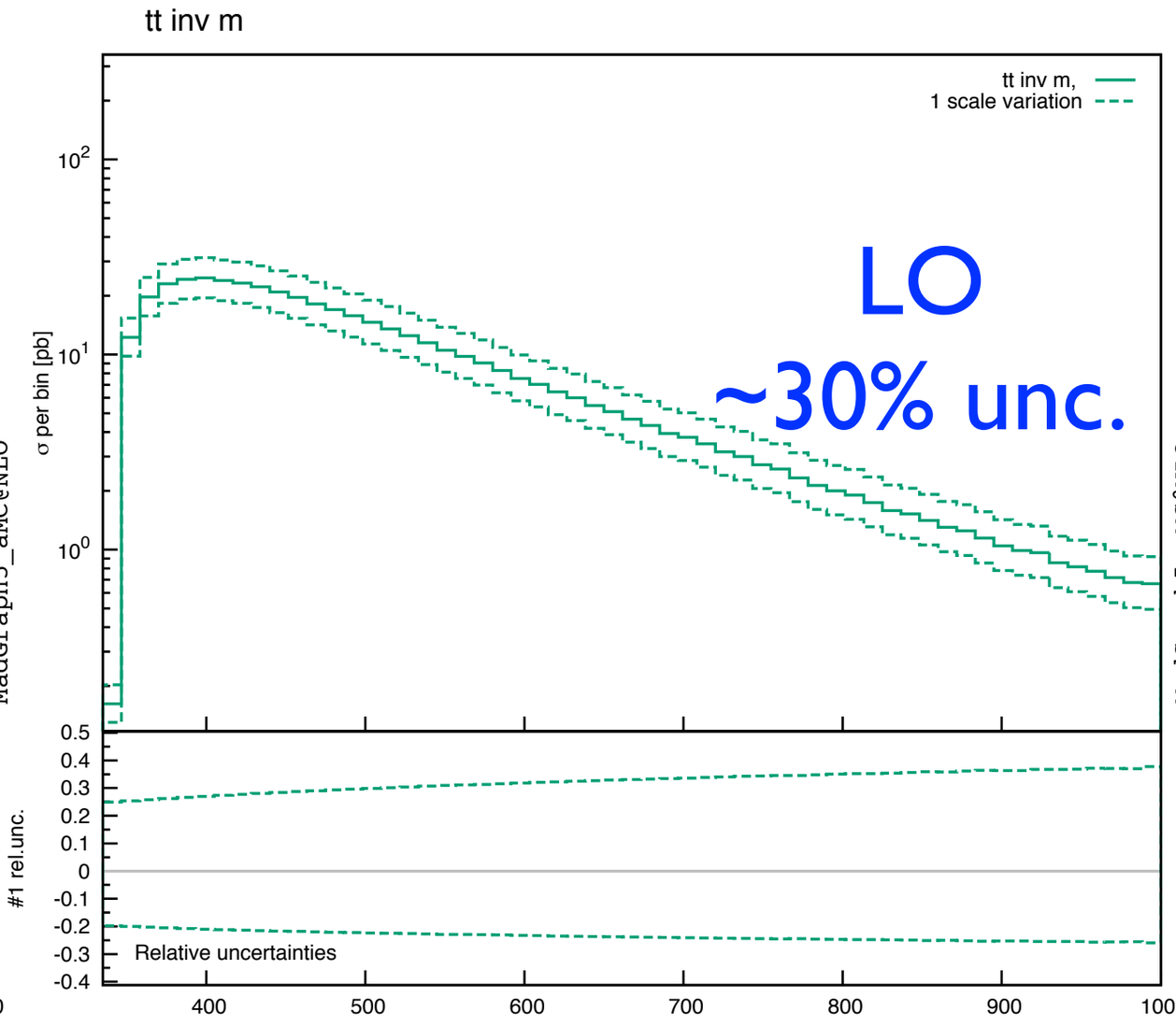
```

Scale uncertainties





Scale uncertainties

$p_T(t\bar{t})$ histogram from NLO run