Derivation of Scale and PDF Uncertainties and Comparison with Data for Jet Cross-Sections with FASTNLO [1]

Preparation:
This exercise can be performed with suitably, i.e. availability of `g++`/`gfortran` compiler and LHAPDF library, prepared Linux systems or with the virtual machine `PDFLHC` that has been set up for this PDF school. For performance reasons it is strongly recommended, however, to attribute about 1 GB of memory to the VM instead of just 1/2 GB. This can be done with `virtualbox` before starting up the VM. Otherwise compiling and linking might become awfully slow.

Furthermore the following steps need to be carried out from within a terminal session:

1. Download the FASTNLO reader software and one of the available FASTNLO cross-section tables from the internet using `wget` either from the indico page of today's tutorial
   https://indico.desy.de/contributionDisplay.py?contribId=12&confId=6225
   or from the fastNLO web page
   ```
   http://fastnlo.hepforge.org/v21/code/fastnlo_reader-2.1.0
   -1273.tar.gz
   http://fastnlo.hepforge.org/v21/tables/fnl1014_v2_all.tab.gz
   ```

2. Decompress the FASTNLO table
   ```
   gunzip fnl1014_v2_all.tab.gz
   ```
   and untar the archive of the reader program:
   ```
   tar xzvf fastnlo_reader-2.1.0-1273.tar.gz
   ```

3. Configure, compile, link and install the reader program:
   ```
   cd fastnlo_reader-2.1.0-1273
   ./configure --prefix=$HOME
   make
   make install
   ```

4. Test the produced executable:
   ```
   rehash
   ```
   `fnlo-cppread -h` → displays the usage and some options
   `fnlo-cppread fnl1014_v2_all.tab` → prints the inclusive jet cross-sections corresponding to the CMS publication [2] with the default parton distributions (PDFs) according to CTEQ6M [3] (cteq6m.LHpdf).

5. If this set is not available in the LHAPDF (**L**es **H**ouches **A**ccord **P**arton **D**istribution **F**unctions) installation of the VM, it and further ones can be downloaded from the LHAPDF projekt page [4]:
   `lhapdf-getdata CT10.LHgrid` [5]
   `lhapdf-getdata NNPDF21_100.LHgrid` [6]
   `fnlo-cppread fnl1014_v2_all.tab ./CT10.LHgrid` → prints the inclusive jet cross-sections of CMS using the CT10 PDF set.

For a detailed evaluation as part of this tutorial you have to program code in `C++`. For this purpose you should read and edit the elaborately commented main program code in `fnlo-cppread.cc` within the subdirectory `reader_cc`. Subsequently you have to recompile and link via `make; make install`.

1. Calculate the relative uncertainty of the jet cross-sections in next-to-leading order (NLO) when varying the renormalization and factorization scales μ_r and μ_f according to the six scale factor combinations (other than [1,1]) predefined in `fnlo-cppread.cc`. A loop over these scale combinations has already been prepared within the code. Note that the uncertainty corresponds to the **maximal** upward and downward deviations from the normal result.

2. Calculate the relative PDF uncertainty of the NLO jet cross-section using the Toy-MC-method required for the NNPDF 2.x PDFs. For this you have to program a loop over all replicas (members 1 to 100) of the NNPDF 2.x PDFs. The central result then is the average cross section and its uncertainty the 1σ-**standard deviation** of the resulting distribution of 100 results (for each observable bin!).

   Note: As detailed in the example code `fnlo-cppread.cc` the LO and NLO results for each observable bin can be accessed via:

   ```cpp
   vector < double > xsnlo = fnloreader.GetCrossSection();
   vector < double > kfac  = fnloreader.GetKFactors();
   vector < double > xslo  = xsnlo;
   for (unsigned int i=0;i<xslo.size();i++){
     if ( abs(kfac[i]) > DBL_MIN ){
       xslo[i] = xslo[i]/kfac[i];
     } else {
       xslo[i] = -1.;
     }
   }
   ```

3. If you still have time you can also compare the calculated NLO cross sections with the data measured by the CMS Collaboration. They are contained in the table used for this tutorial and can be printed out via
   `fnloreader->PrintCrossSectionsData();`.

A graphical representation of this comparison could look like in Figure 1 from [7].
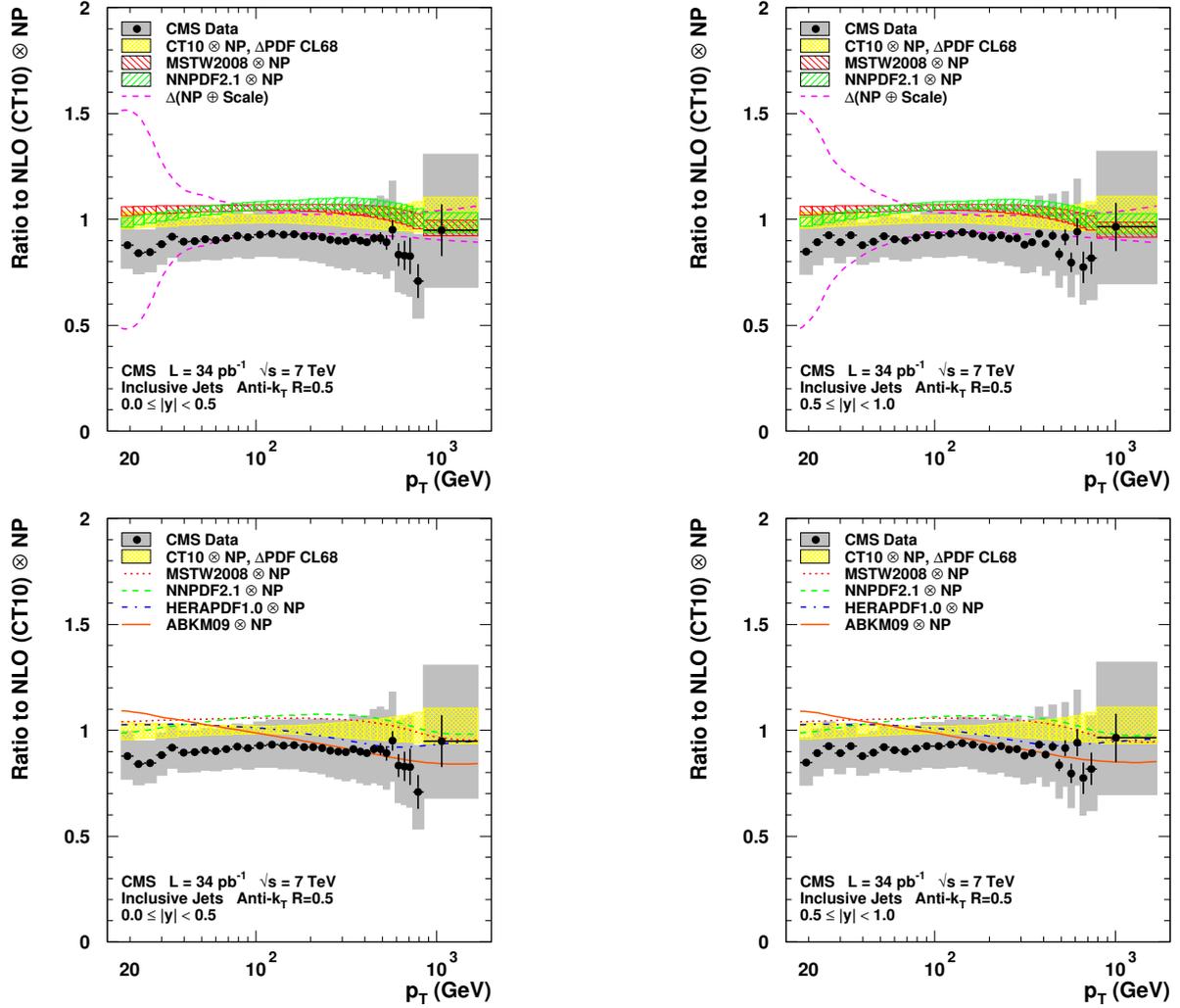
Figure 1: CMS inclusive jet data for $|y| < 0.5$ (left) and $0.5 \leq |y| < 1.0$ (right) are presented vs. p_T with statistical (error bars) as well as systematic uncertainties (grey band) as ratio to NLO using the CT10 PDFs. Additional predictions are shown using the MSTW2008 and NNPDF2.1 PDFs (top). PDF uncertainties are displayed as colored bands. The central results of four additional PDFs are also shown together as lines in one plot (bottom). Common theoretical uncertainties from scale choices and NP corrections are indicated by dashed magenta lines (top and middle).

References

[1] fastNLO Collaboration, "Theory-Data Comparisons for Jet Measurements in Hadron-Induced Processes", `arXiv:1109.1310`.

[2] CMS Collaboration, "Measurement of the Inclusive Jet Cross Section in pp Collisions at $\sqrt{s} = 7$ TeV", *Phys. Rev. Lett.* **107** (2011) 132001, `doi:10.1103/PhysRevLett.107.132001`, `arXiv:1106.0208`.

[3] J. Pumplin, D. Stump, J. Huston et al., "New generation of parton distributions with uncertainties from global QCD analysis", *JHEP* **07** (2002) 012, `doi:10.1088/1126-6708/2002/07/012`, `arXiv:hep-ph/0201195`.

[4] M. R. Whalley, D. Bourilkov, and R. C. Group, "The Les Houches Accord PDFs (LHAPDF) and Lhaglue", `arXiv:hep-ph/0508110`.

[5] H.-L. Lai et al., "New parton distributions for collider physics", *Phys. Rev.* **D82** (2010) 074024, `doi:10.1103/PhysRevD.82.074024`, `arXiv:1007.2241`.

[6] R. D. Ball et al., "Impact of Heavy Quark Masses on Parton Distributions and LHC Phenomenology", *Nucl. Phys.* **B849** (2011) 296–363, `doi:10.1016/j.nuclphysb.2011.03.021`, `arXiv:1101.1300`.

[7] CMS Collaboration and K. Rabbertz, "Comparison of Inclusive Jet and Dijet Mass Cross Sections at $\sqrt{s} = 7$ TeV with Predictions of perturbative QCD", CMS Note 2011-004, CERN, Geneva, (June, 2011).