Scale Variations as Theoretical Uncertainties

Group E

The CMS collaboration measured differential distributions for top pair production in the lepton+jet channel[1], presenting parton level results.

1. Use MATRIX to compute NNLO theoretical predictions for the following distributions:

   - invariant mass of the $t\bar{t}$ pair, $m_{t\bar{t}}$ (see Fig.16 of Ref.[1]);
   - absolute rapidity of the $t\bar{t}$ pair, $|y_{t\bar{t}}|$ (see Fig.16 of Ref.[1]);
   - **BONUS:** double differential distribution of the invariant mass of $|y_{t\bar{t}}|$, in $m_{t\bar{t}}$ bins (see Fig.22 of Ref.[1]).

   Fix the value of the top mass to $m_t = 173.3$ GeV and use the NNPDF31 set of parton distribution functions with $\alpha_S(m_Z) = 0.118$. Consider different choices for the central value μ_0 of the renormalization and factorization scale, choosing from the following set:

   $$\{H_T/2,\ H_T/4,\ m_t,\ m_{t\bar{t}}/2,\ m_{t\bar{t}}/4,\ m_{T,t},\ m_{T,\bar{t}},\ m_{T,t}/2,\ m_{T,\bar{t}}/2\}\ ,$$

   where $m_{T,t(\bar{t})}$ is the transverse mass of the (anti-)top quark, and H_T is defined as

   $$H_T = m_{T,t} + m_{T,\bar{t}}\ .$$

2. Plot the differential distributions obtained for different central scale choices. What do you observe? Which ones exhibit a faster perturbative convergence? Which ones provide a more reliable estimate of the theoretical uncertainties?

3. Compare the theoretical predictions with experimental data. How does the central scale choice affect the comparison? Do you observe agreement between theory and experimental measurements? If not, can you think about possible justifications?

Tips:

- A good central scale choice is of the same order as the characteristic hard-scattering scale. It depends on the differential distribution under consideration. With MonteCarlo event generators you are usually able to run several distributions simultaneously, but only one scale at a time. For this reason it is always convenient to find a scale which is able to mimic the behaviour of the characteristic hard scale for different distributions at the same time.
- Some of the proposed central scale choices are not between the ones listed in `paramter.dat`. Nevertheless, they are all already implemented in:
  `MATRIX_v2.1.0/prc/ppttx20/user/specify.scales.cxx`.
- Remember that the precision you require to MATRIX will be satisfied at the level of the inclusive cross section. You might obtain lower precision in specific bins of the distributions.
- NNLO runs and high precision NLO runs are most likely beyond the time and machine constraints of this school. Discuss with your project leader your plans with more ambitious runs, that can be run on dedicated clusters.
- MATRIX provides default plots generated with gnuplot. In `/var/bnd/theo/plot_generation` you find a default script in Python to generate plots from the MATRIX output, that you can customize.

References

[1] Albert M Sirunyan et al. Measurement of differential cross sections for the production of top quark pairs and of additional jets in lepton+jets events from pp collisions at $\sqrt{s} = 13$ TeV. *Phys. Rev. D*, 97(11):112003, 2018.