Exercise to Matching and Merging (lecture 5)

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1 Exclusive W+jet production

In your Pythia installation there is a main02.cc in the example directory for Z Production at Tevatron ($p\bar{p}$) @ 1.96 TeV.

1. Modify the file to simulate $W^{\pm}$ production at 7 TeV LHC (pp).
   Also search the online manual for the following and modify for your needs:

   - `PhaseSpace:mHatMin` and `PhaseSpace:mHatMax`. Actually, for $W + 1jet$ these limits will not work the same way, so you can already now replace them e.g. with `24:mMin = 60.` and `24:mMax = 100.` to restrict the W mass accordingly.
   - `PartonLevel:MPI` , `HadronLevel:all` and `BeamRemnants:primordialKT` .

   Remember to search for $W^{\pm}$ in the pythia.event (what is the id?).

2. Plot the transverse momentum p_T of the $W^{\pm}$-boson.
   For an absolute normalization of $\mathrm{d}\sigma/\mathrm{d}p_{\perp}$ you can use that `pythia.info.sigmaGen()` gives you the integrated σ.
   Advanced: Use `pTW.rivetTable("PS.dat");` to write out the diagram and plot with an external program, e.g. python matplotlib.

3. Now make a copy the modified file (in order to compare the results later) and modify the main program to calculate $W + 1jet$ at LO:

   - `pythia.readString("WeakBosonAndParton:qqbar2Wg On");`
   - `pythia.readString("WeakBosonAndParton:qg2Wq On");`
   - `pythia.readString("PhaseSpace:pTHatMin = .5");`
   - `pythia.readString("PhaseSpace:pTHatMinDiverge = .5");`

   Plot the transverse momentum p_T!

4. Create an α_S object `AlphaStrong alphaS;` and initialize with a value `alphaS.init(0.130);`.

5. Weight the events with:

$$\mathtt{w} = \exp\left(-2 \cdot \frac{C_F \alpha_S(p_T^2)}{2\pi}\left[\frac{1}{2}\log^2(p_T^2/M_W^2) - \frac{3}{4}\log(p_T^2/M_W^2)\right]\right)$$

   and `w*=alphaS.alphaS(`p_T^2`)/pythia.info.alphaS();` by filling the histograms with: `pTW.fill( pythia.process[iW].pT() , w);`. Discuss your findings. What approximations did we use? Why is this a crude approximation? What happens if you use $\alpha_S(M_W^2)$ in the exponent?
   Advanced: Try to start with the function for the quark Sudakov in the lecture and replace the q integration with an integration over α_S.

2 Monte Carlo Scheme α_S and NLO merging

The LO splitting functions are in the limit $z \to 1$ given by,

$$P_{a\to ag}(z) = \frac{2C_a}{1-z}$$

where $C_g = C_A = 3$ and $C_q = C_F = 4/3$. The next to leading order splitting functions are in the same limit proportional to

$$P_{a\to ag}(z) = \frac{2C_a}{1-z}(1 + K_g \frac{\alpha_S}{2\pi})$$

with

$$K_g = C_A\left(\frac{67}{18} - \frac{\pi^2}{6}\right) - T_F\frac{10}{9}\ .$$

As gluon emissions (off quarks and gluons) are the dominant contribution it is desirable to include the factor in the usual parton shower process.

1. Calculate the factor K_g.

2. If we define $\alpha_S^{MC} = \alpha_S^{\overline{MS}}(1 + K_g\frac{\alpha_S^{\overline{MS}}}{2\pi})$, what is the value of $\alpha_S^{\overline{MC}}$ with a $\alpha_S^{\overline{MS}} = 0.118$.

3. If the parton shower algorithm and the LO merging is using α_S^{MC} this affects the α_S ratios. In a NLO calculation with gluons legs and calculated in the $\overline{MS}$ scheme, this also produces additional factors proportional to K_g. How do we need to modify our NLO merging, not to double count the effects?