Problem 1. Higgs production at the Tevatron. The main production process used for a discovery of a light ($m_h < 140 \text{ GeV}$) Higgs boson at the Tevatron is $p\bar{p} \rightarrow Wh$. In this exercise we shall calculate its cross-section using CalcHEP.

(a) Start up CalcHEP and generate the diagrams for $p\bar{p} \rightarrow W^+h$ and $p\bar{p} \rightarrow W^-h$. Without doing any calculations, try to guess and rank the first few dominant subprocesses according to their importance.

(b) Calculate the cross-section for $p\bar{p} \rightarrow W^\pm h$ at the Tevatron ($E_{CM} = 2 \text{ TeV}$) as a function of the Higgs mass $m_h$, for $100 < m_h < 200 \text{ GeV}$. Hint: The cross-section is a slowly varying function of $m_h$, so you will only need to compute it at 3-4 points.

(c) Check your guesses from (a) against the numerical results from (b).

Problem 2. Higgs production at the Tevatron: signal versus background. For a Higgs discovery in $p\bar{p} \rightarrow Wh$ at the Tevatron, one makes use of the decays $W \rightarrow \ell\nu$ and $h \rightarrow b\bar{b}$. The final state signature is therefore $\ell\nu b\bar{b}$. The main background is $Wb\bar{b}$ production, where the $b$’s were produced through a gluon, photon or a $Z$. On the same plot, show the $b\bar{b}$ invariant mass distribution $M_{b\bar{b}}$ for the $Wh$ signal and the $Wb\bar{b}$ background. Notice that because of the very small Higgs width $\Gamma_h$, the signal will peak very sharply at $M_{b\bar{b}} = m_h$. In reality, however, the energy of the $b$-jets is not perfectly measured, which results in an uncertainty in $M_{b\bar{b}}$ of order 10%. An easy way to account for the poor mass resolution and thus make our plot more “realistic”, is to simply inflate the Higgs width $\Gamma_h$ to $0.1m_h \sim 12 \text{ GeV}$.

Hint: You may need to use the option “regularization” to constrain $M_{bb}$ near the s-channel gluon, photon, $Z$ or $H$ resonances.

Problem 3. Higgs production at the LHC. Repeat Exercise 1, but for the case of Higgs production in vector-boson fusion at the LHC ($pp$ collider, $E_{CM} = 7 \text{ TeV}$).