1. Search for the Higgs boson in the di-photon decay channel

The process $pp \rightarrow H \rightarrow \gamma\gamma$ was very important for the discovery of the Higgs boson at the LHC.

Under the usual location

http://portal.uni-freiburg.de/jakobs/Lehre/ss-15/hadron-collider,

you can find the starting analysis scripts together with two root files. The first one $ggFHgamgam.root$ contains simulated events of Higgs bosons produced in gluon fusion at $\sqrt{s} = 8$ TeV. The file $gamgam.root$ contains events of the di-photon continuum, also at $\sqrt{s} = 8$ TeV, which we consider as a background process.

(a) Select events containing at least 2 photons with $|\eta| < 2.37$. The leading photon, i.e., the photon with the highest transverse momentum in the event, is required to have a $p_T > 40$ GeV, the sub-leading photon to have a $p_T > 30$ GeV. Plot the distributions of the transverse momenta of the leading and sub-leading photon for signal and background. [2 points]

(b) Plot the invariant mass of the di-photon pair $m_{\gamma\gamma}$. Normalize both histograms to the number of expected events and stack them on top of each other.

Assume an integrated luminosity of $L = 20$ fb$^{-1}$. The signal cross section is given by $\sigma(pp \rightarrow H) = 19.2$ pb and the branching ratio of the Higgs boson to two photons is $BR(H \rightarrow \gamma\gamma) = 0.0023$.

Getting the correct cross section of the background process $pp \rightarrow \gamma\gamma$ is a bit more involved. For simplicity, just assume that the provided sample has $\sigma(pp \rightarrow \gamma\gamma) = 9$ pb. [2 points]

(c) Choose a mass range of the $m_{\gamma\gamma}$ distribution and compute the ratio of expected signal events $s$ to the number of expected background events $b$.

To quantify the significance of the signal you can use the Asimov significance $Z^A_0$. It is given by the following formula:

$$Z^A_0 = \sqrt{2 \cdot [(s+b) \ln(1+s/b) - s]}.$$

Try to optimize the mass range with respect to the significance. What is the best Asimov significance that you achieve and for which region of $m_{\gamma\gamma}$? [3 points]

Please hand in the resulting distributions together with appropriate explanations.
2. Top-quark decay

The muon decay width $\Gamma_\mu$ can be very roughly estimated using dimensional arguments. The Feynman diagram involves two weak vertices, which means the width will be proportional to $G_F^2$ (\(G_F\) being the Fermi constant).

(a) Based ONLY on dimensional arguments, write down an expression for $\Gamma_\mu$ as a function of $G_F$ and the muon mass $m_\mu$.

Note that the estimate is quite wrong, as in the exact calculation there is a large, dimensionless factor $1/192\pi^3$ which is involved in the expression.

With similar arguments, one can compute the width $\Gamma_t$ of a top quark decaying into $Wb$.

(b) Why is the $t \rightarrow Wb$ decay in practice the only decay channel of the top quark?

(c) Based ONLY on dimensional arguments, write down an expression for $\Gamma_t$ as a function of $G_F$ and the top-quark mass $m_t$.

(d) The result of the exact LO calculation is that a factor $1/8\pi\sqrt{2}$ has to multiply the expression obtained at the previous point. Write down the numerical estimate for $\Gamma_t$. 