1. Jet calibration

In this exercise we will learn how \( pp \rightarrow \gamma \) jet events can be used to determine the jet energy scale. We will make use of the fact that the transverse momenta of the outgoing parton and the photon are balanced in the partonic \( 2 \rightarrow 2 \) process. The reconstructed jets can therefore be calibrated using the photons as a reference object. Remember that photons are reconstructed in the electromagnetic calorimeters with a considerably better energy resolution compared to hadrons measured in the hadronic calorimeters.

You will find the necessary files for this exercise on the web page of this course: [http://portal.uni-freiburg.de/jakobs/Lehre/ss-15/hadron-collider](http://portal.uni-freiburg.de/jakobs/Lehre/ss-15/hadron-collider). PythiaGammaJet.root contains the events for the analysis. Take a look at GammaJetAnalysis.h to find out which branches are in the ROOT file or use a TBrowser for this. The branches photon\_pt, photon\_eta, ... and jet\_pt, ... contain the information about all reconstructed photons and jets of the event (above a certain \( p_T \) threshold). Note that all of them are vectors which are ordered by \( p_T \). The selection should be implemented in the Loop() method that can be found in the GammaJetAnalysis.C. The program can be run as learned in the last problem set.

(a) Plot the distributions of: the \( p_T \) of the leading photon, the \( p_T \) of the leading jet, the \( p_T \) of the sub-leading jet. Here, “leading” simply means the jet/photon with the highest transverse momentum in the event and “sub-leading” jet being the one with the second-highest \( p_T \).

Also make a plot of the difference of the azimuthal angle between the leading photon and jet: \( \Delta \phi(\gamma, \text{jet}) \). Make sure the result takes on values in the interval \([0, \pi]\).

[2 points]

(b) Implement the following selection cuts: \( p_T(\gamma) > 20 \text{ GeV}, p_T(\text{leading jet}) > 20 \text{ GeV} \). Add a jet veto to the selection: discard events with \( p_T(\text{sub-leading jet}) > 20 \text{ GeV} \) or \( \Delta \phi(\gamma, \text{jet}) < 2.8 \). Why is such a veto cut necessary? [2 points]

(c) Plot the transverse momentum balance \( \rho := \frac{p_T(\text{leading jet}) - p_T(\gamma)}{p_T(\gamma)} \).

[2 points]

(d) Correct the \( p_T(\text{leading jet}) \) with a constant scale \( C \) to result in a calibrated jet with \( p_T^{\text{calib}}(\text{leading jet}) = C \cdot p_T(\text{leading jet}) \).

Derive \( C \) from the mean of the \( \rho \) distribution. Make plots of \( p_T^{\text{calib}}(\text{leading jet}) \) and \( \rho^{\text{calib}} \). [3 points]

(e) Redo (d) with \( C \) derived by fitting a Gaussian distribution to the \( \rho \) distribution. [3 points]
(f) Redo (e) with $C = C(p_T)$ depending on the transverse momentum of the photon:

$C_1$ for $20 \text{ GeV} < p_T(\gamma) < 30 \text{ GeV}$, $C_2$ for $30 \text{ GeV} < p_T(\gamma) < 40 \text{ GeV}$ and $C_1$ for $p_T(\gamma) > 40 \text{ GeV}$. [3 points]