Exercises for the Calorimeter Reconstruction and Machine Learning Workshop 2024

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1. X_0 is the radiation length of an electromagnetic shower given by

$$X_0 = \frac{A}{4\alpha N_A Z^2 r_e^2 \ln \frac{183}{Z^{1/3}}} \quad . \tag{1}$$

Plot X_0 as a function of A and Z and put points for the materials in our simulation.

2. E_c is the critical energy at which the bremsstrahlung and ionization rates are equal and can be approximated by

$$E_c = \frac{800\,\mathrm{MeV}}{Z + 1.2} \quad . \tag{2}$$

Verify this approximation for 3 - 4 choices of energies using simulation. How can we do this with our given tools?

3. The number of radiation lengths an electromagnetic particle travels in a material until the shower maximum follows the relation

$$t_{max} \propto \ln E_0/E_c \quad . \tag{3}$$

A rule of thumb for the length in which 99% of the initial energy is deposited in the material is

$$L(99\%) = (t_{max} + 0.08Z + 9.6)[X_0] \quad . \tag{4}$$

   a) Verify the position of t_{max} for 3 - 4 choices of energies in simulation
   b) Verify $L(99\%)$ in simulation for a 50 GeV shower
   c) How many X_0 are need to capture 95% of the initial energy? (Careful: the simulation also includes processes such as ionisation / excitation / Compton Scattering / Rayleigh Scattering)

4. The Moliere radius describes the transversal expansion of an electromagnetic shower, mostly by low-energy electrons. What is the Moliere radius of Pb or $PbWO_4$? What does that mean for our calorimeter?

5. (optional): simulate showers in a calorimeter highly granular in $x - y$ and verify the Moliere radius qualitatively.

6. Compare the energy deposition in the same thickness for different scintillator materials in our G4Calo simulation package.

7. CMS and ATLAS have two different approaches when it comes to calorimeter designs.

   a) Verify qualitatively the two calorimeter designs in simulation with a simple energy sum and a DNN regression for energy reconstruction.

   b) Compare the overall energy resolution of the two designs using a shower at 50 GeV. What do you find?

   c) Store your code in a module that is callable, you will need it again later.

8. Write a function that also tracks the total material cost of the calorimeter.

9. Build an optimal EM calorimeter for showers between 1 and 100 GeV (no transversal granularity). Don't spend more than 50.000 CHF.