Computing Methods for Physics
10 May 2021

version 1

You must submit your exam by **Monday 10 May at 13:30** following the instruction at http://www.roma1.infn.it/people/rahatlou/cmp/

Electron energy loss in matter

The goal is to estimate the maximum penetration of an electron beam (10^4 electrons) in a lead (Pb) target by taking into account Bremsstrahlung, above the critical energy, and energy loss by ionisation. Use a step size of 100 microns to estimate the probability of interaction and the average energy loss by each electron.

Reminders

- For E > E_c (critical energy) electrons loose energy mainly by Bremsstrahlung. The probability of an electron not-interacting after a penetration length **x** is an exponential e^{-x/X_0}, where $\mathbf{X_0}$ is the interaction length. The energy of the electron after a penetration length x is $E(x) = E_0 \cdot e^{-x/X_0}$, where $\mathbf{E_0}$ is the initial energy of the electron.
- Below the critical energy, you can estimate the average energy loss by ionisation with the approximate Bethe-Bloch formula
$$-\frac{dE}{dx} = \mathscr{C}\rho \frac{Z}{A}\frac{1}{2}\frac{1}{\beta^2}\left[\ln\frac{4\,m_e^2\beta^4\gamma^4}{\bar{I}^2} - \beta^2 - \frac{\delta}{2}\right]$$
where $\mathscr{C} = 0.3\,\mathrm{MeV\,g^{-1}\,cm^2}$, and β, γ are the parameters of the electron, and the lead parameters are provided in the table.
- A particle can loose only its kinetic energy $K_e = E_e - m_e$. The electron mass is 0.511 MeV

	Density [g/cm³]	<I> [eV]	E_c [MeV]	Radiation Length X_0 [cm]	Interaction Length X_I [cm]	Z	A	δ
Pb	11.35	823	7.4	0.56	17.59	82	207	0.6

In order to estimate the maximum penetration x_{max}, for each electron passing through Pb consider the following steps. It is mandatory to use functions (or possibly appropriate classes) whenever possible.

1. Based on the electron energy decide which energy loss mechanism is to be considered
2. If Bremsstrahlung, evaluate the probability of interaction and use a random number to decide if an interaction occurs. In case of interaction, compute the new electron energy

3. If ionisation, compute the average energy loss with Bethe-Bloch. Extract the actual energy loss from a Gaussian distribution with its mean given by the Bethe-Bloch formula, and a width of 5%. Compute the new energy.
4. When the electron has lost all its kinetic energy, compute the maximum penetration x_{max}
5. Compute the average and RMS of the distribution of x_{max} and print them with an informative message on the screen.
6. Repeat the simulation for electrons of 10 MeV, 1 GeV, 100 GeV
7. Provide a 1D histogram of the distribution of x_{max} for each energy and save the plot as a pdf file named, respectively, **`xmax-10mev.pdf`**, **`xmax-1gev.pdf`**, and **`xmax-100gev.pdf`**
8. Provide a plot showing the average of x_{max} as a function the electron energy (10 MeV, 1 GeV, 100 GeV) on the x axis and save the plot as **`xmax-energy.pdf`**

You can use C++/ROOT or python for this test.

The evaluation will take into account the following aspects of your code: use of functions, proper arguments and return types; use of C++/python objects and data formats; use of object-oriented programming instead of C-style loops and arrays; ; compilation or linking errors; correct physics calculation; correct physical units; proper legend, axis labels and units on the plots; significant digits (not more than 2).