COMPUTING METHODS FOR PHYSICS

11 SEPTEMBER 2019

You must submit your exam by **Friday Sep 13 at 17:00** following the instruction at http://www.roma1.infn.it/people/rahatlou/cmp/

Bethe-Bloch formula

The Bethe-Bloch formula provides an accurate estimate of the average energy loss of relativistic particles due to ionisation (dE/dx) in mater. The scope of this exercise is to simulate the distribution of dE/dx for protons in lead (Pb). The dimensions of the detector or not relevant for this exercise. You need to use the ROOT libraries.

1. Generate 10^5 protons with momentum in the range [300 MeV, 1 TeV]
2. For each proton compute the average energy loss <dE/dx> according to the Bethe-Bloch formula
3. The effective energy loss dE/dx for the particle must be extracted from a Gaussian distribution with mean of <dE/dx> and a width of

$$10\% - 5\% \times \frac{\beta\gamma}{1000}$$

   where $\beta\gamma$ is that of the particle.

4. Make a 2D plot of dE/dx as a function of momentum for all protons using the ROOT TH2F class. Use appropriate binning, axis scale, and draw options to obtain a good-looking plot and save it as PDF.
5. Use the ROOT TProfile class to plot the mean dE/dx and its standard deviation in bins of momentum for all protons. Store a copy of the plot as a PDF file.

Provide instructions for compiling your code in the comments at the beginning of `exam.cc` .

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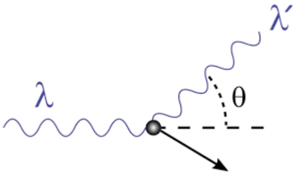
Spectrum of Compton Scattering

Cesium-137 is a radioactive isotope which decays via beta emission (half life of 30.2 years) to a an excited metastable state of Barium ^{137m}Ba. This state decays with a half-life of 153 seconds to the ground state ^{137}Ba emitting a photon with energy E_0 = 662 keV. We want to study the spectrum of ^{137}Cs and the effect of Compton scattering.

6. Generate 10000 photons with energy E_0.
7. Each photon is detected with a NaI crystal which has a resolution of 3%. Use a Gaussian convolution and plot the distribution of detected energy E_i of all photons. Make sure reasonable binning are used for the histogram and labels and units are added. The expected distribution should be a Gaussian entered at E_0.
8. Assume that each photon has a 60% probability of undergoing Compton scattering in the crystal.
9. The energy E_f of the photon after the scattering is given by where me is the mass of the electron (511 keV) and θ is the angle of the photon after scattering as shown in the figure.

$$E_f = \frac{E_i}{1 + (E_i/m_e)(1 - cos\theta)}$$

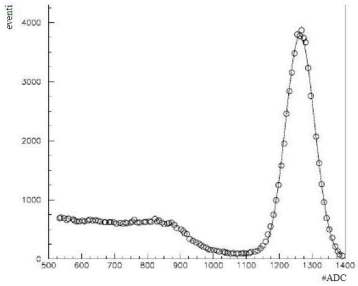


10. The angle θ must be generated casually assuming that the differential cross section

$$\frac{d\sigma}{d\cos\theta} \propto 1 + \cos^2\theta$$

If you do not know how to do this, you can generate a flat distribution for θ (with a penalty).

11. Plot the distribution of for all 10000 photons. You should still see a peak around E_0 and a continuous distribution (a Fermi-Dirac shape) for E_f<0.



Save a PDF file for each of the above 2 plots. Use comprehensions and dictionaries to implement the simulation and plotting the required plots. Define a function `Compton` (with proper arguments and return values) to simulate the scattering for each photon of energy E_i at each step for each particle.

Evaluation will be based on use of python features and data structures, comprehensions (instead of C-style for loops), dictionaries, NumPy objects, labels, units, and clarity of plots.