# The GEANT4 problem that will be on the Take-Home Final

**Due:** with the take-home final at the end of the semester. Just putting it out there in case you want to get it done before the take-home is assigned.

**Another warning:** the take-home will involve a fair bit of fitting spectra. It would be wise of you to make sure you have a flexible fitting routine at your disposal, and make sure you get the problems on Homework #4 which involve fitting. Heck, start now fitting Gaussians and exponentials if you can, and try to make sure your program can do a Poisson fit, not only one assuming Gaussian statistics.

## 1. Multiple scattering with GEANT4:

I know this problem is time-expensive. This is why I tried to force you to start early and why I'm posting the problem already. No modern nuclear-physics experiment (that I know of) doesn't make use of `GEANT4` or some other Monte Carlo simulation to interpret the results. It will not only serve you in an academic career to know how to install, code and run `GEANT4`, but even in other career paths: I've seen positions at GE advertised where experience with `GEANT4` is the main qualificiation!

You are designing an experiment where part of what you want to measure is the position of $\beta^-$ particles following a decay from a point-like source to determine its momentum. The range of energies of the electron is up to $T_\beta = 5$ MeV, and the position resolution (FWHM) of your detector is determined by the strip width of 1.00 mm, independent of the particle type or energy. You want to be able to use the position and energy you observe to calculate the momentum of the particle, and you want to go to as low a $\beta$ energy as possible.

Your geometry is almost the same as the one defined in homework #2: the source is 4.5 inches away from a 0.525-inch thick collimator (a stainless-steel flange) whose rectangular opening only lets through $\beta$s that are directed toward your $40 \times 40 \times 0.130$ mm$^3$ Si-strip detector, which is mounted 5 mm behind the collimator. Now, to separate the ultra-high ($10^{-10}$ Torr) vacuum of the decay chamber from dry air at 1 atm (which the detector sits in), you need to use a thin foil. The idea is again outlined in the figure.

You are charged with considering two foils which can handle the pressure difference: 1 thou (0.0254 mm) thick 304 stainless steel, or 5 thou (0.127 mm) thick pure beryllium. The beryllium, being a very dangerous material to work with and difficult to make very pure, is much more expensive ($\sim$ \$10k instead of $\sim$ \$500). The measurement of the position must be better than 2.00 mm FWHM for the momentum to be deduced well enough. You endeavour to answer this by considering an initial pencil-beam directed along the $\hat{x}$-axis and estimating the distribution of hits on the detector, again as schematically outlined in the figure above.

(a) Stainless steel 304 is 72% Fe, 18% Cr, 8% Ni and 2% Mn which have radiation lengths of 13.84, 14.94, 12.68 and 14.64 g/cm$^2$ respectively. What is the radiation length of 304SS?

(b) Look up the radiation lengths and densities of beryllium and dry air at 1 atm from the PDG website and say what they are.

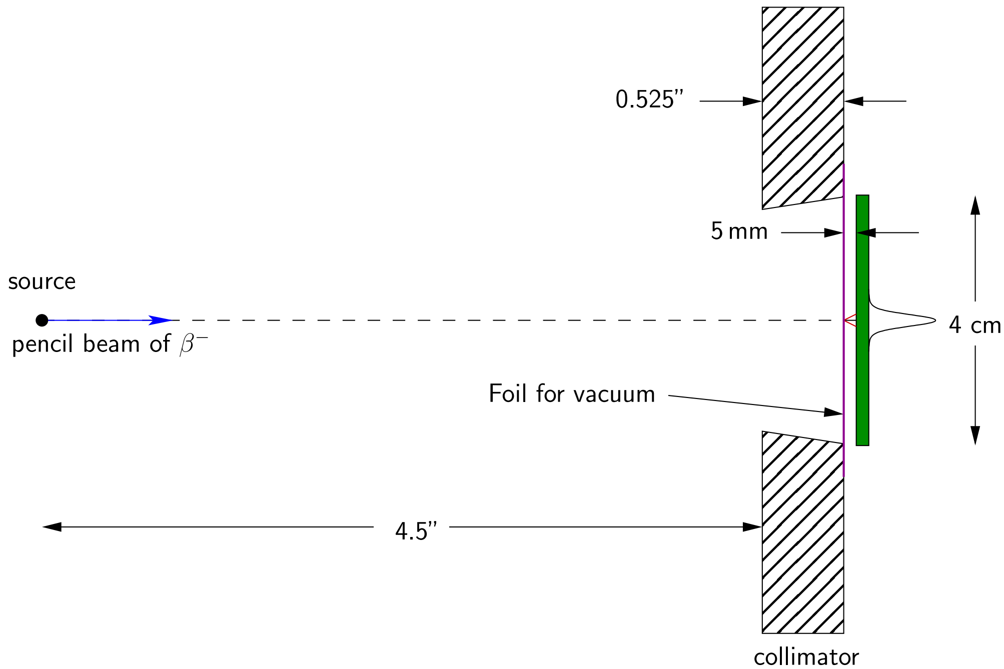


Figure 1: Geometry for the multiple scattering problem.

You must run a Monte Carlo simulation at various $T_e$'s to answer the following questions. The results should all be functions of energy, running the MC at 0.5, 1, 1.5, ..., 5 MeV. You will surely want to use `GEANT4` as it is the most widely-used package and will likely serve you best in your career, but just as good at answering this question [better, actually!] are `PENELOPE` and `EGSNRC`.

(c) Estimate the FWHM of the distribution on the detector caused by the air, showing its contribution can be neglected. I would do this by simply removing the foil and looking at the positions of the hits in the Si detector (unbinned, so *not* including the finite strip widths), and then plotting the FWHM as a function of the initial kinetic energy of the electron.

(d) Estimate the total FWHM of the Gaussian distribution of position the detector will read in one dimension (*i.e.* the $\hat{y}$ distribution) using the stainless foil and compare that to using the beryllium foil. (Again, *not* factoring in the 1-mm wide strip position but the actual position).

(e) How low in $\beta$ energy can we go with the stainless foil such that the momentum can be adequately reconstructed? Here is where you factor in the 1 mm strip width, which eventually *will* limit your reconstructed angle. Do the same for the beryllium. Do you think the beryllium foil is worth the extra cost? In a nutshell: do you tell your advisor to "Suck it up, Buttercup" and buy the more expensive Be foil, or can the group put the $10k towards a rocking new digitizer?