README.md

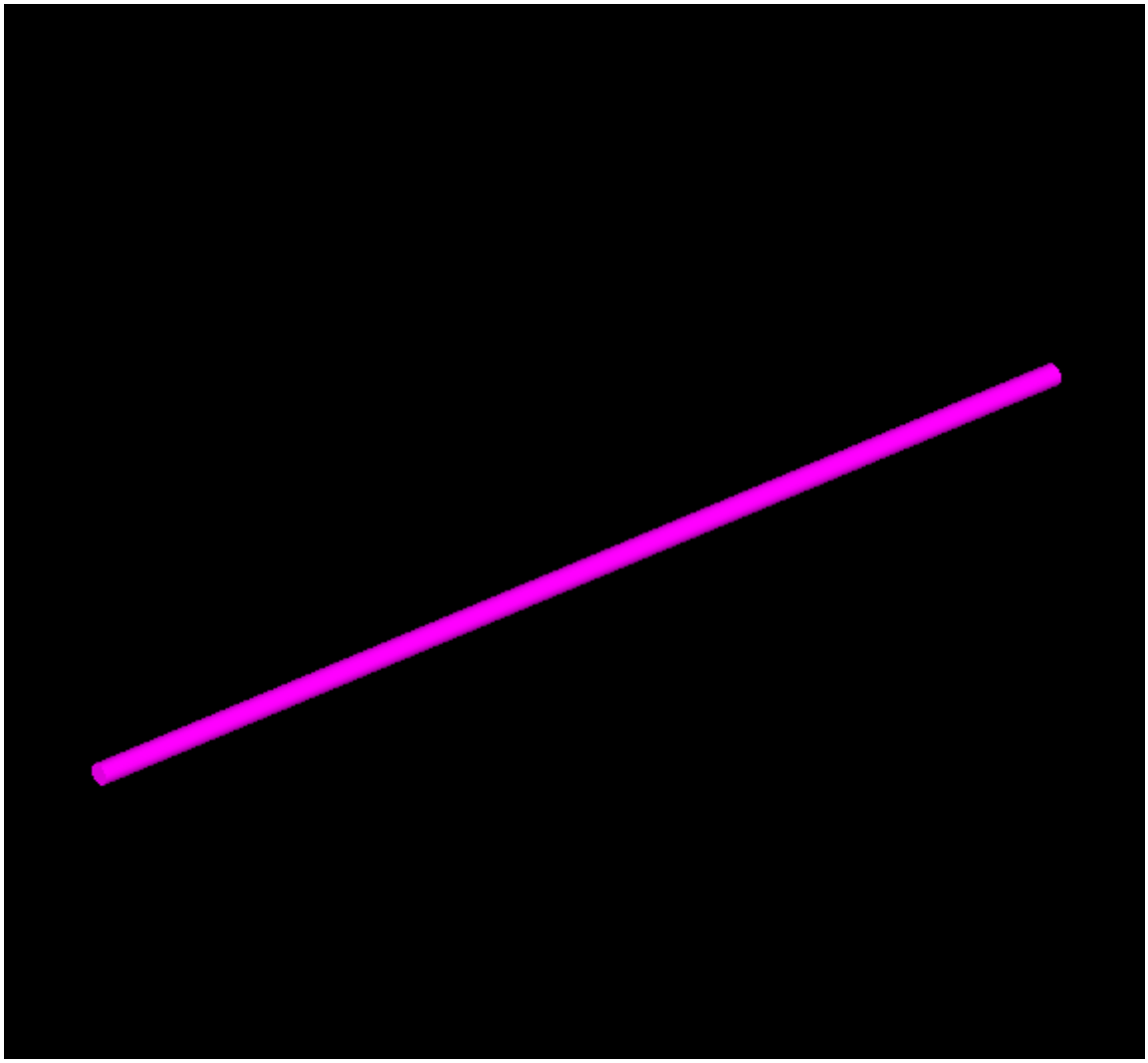
Compton/Rayleigh scattering and X-ray polarimetry

Polarization measurements of astrophysical sources in X-ray energies is an area of great scientific interest, but not many measurements until recently. Measurement of polarization in X-ray energies above ~10 keV makes use of the characteristics of Rayleigh and Compton scattering of the incident photons in detector systems. In this exercise, we will carry out simple Geant4 simulations to understand basic properties of Rayleigh/Compton scattering and how they are dependent on the polarization of incident beam and then do simulations of a simple X-ray polarimeter.

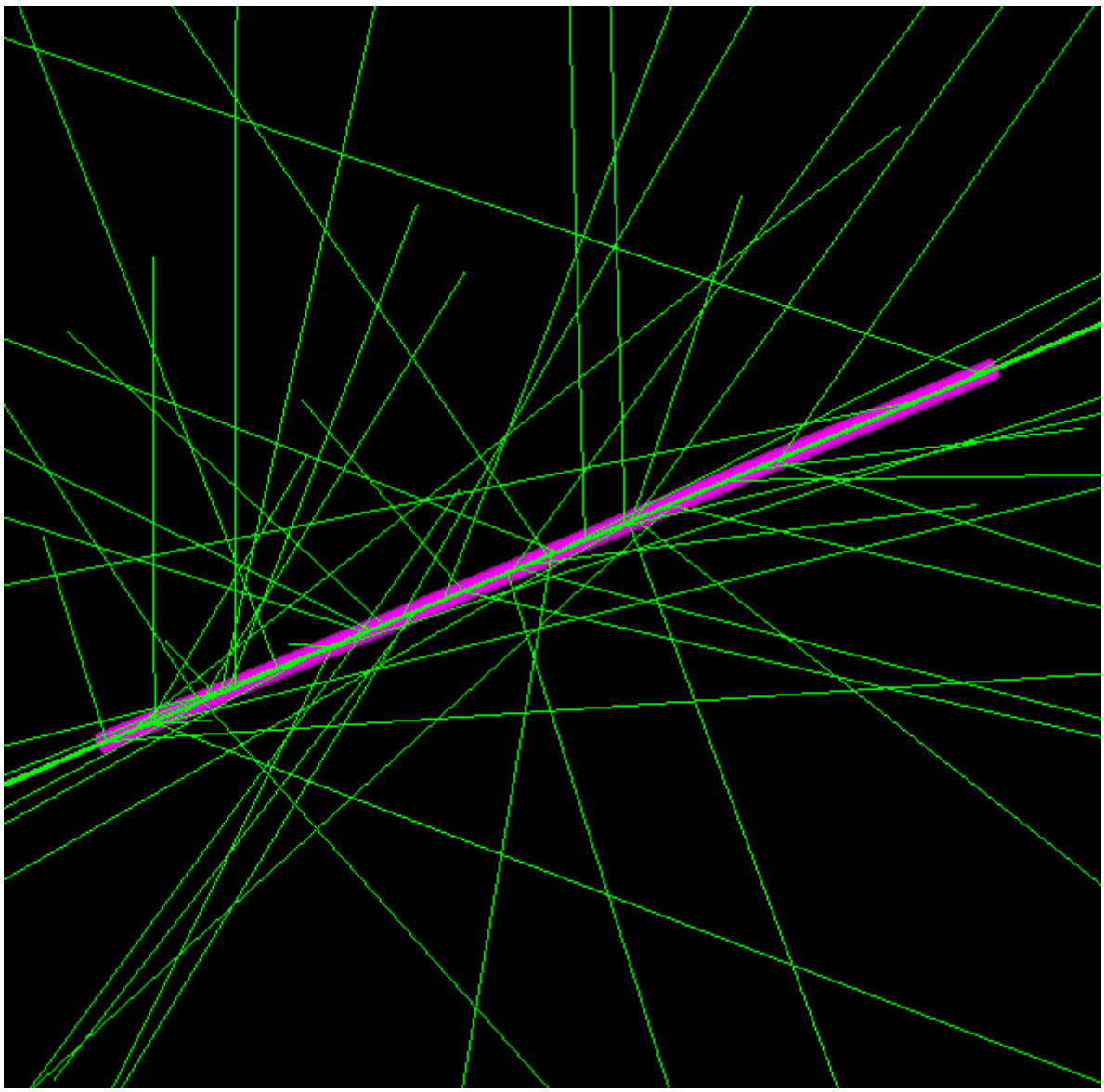
Problem 1: Scattering angle distributions

(**a**) Setup a Geant4 simulation as follows:

- Detector Construction: A plastic scintillator rod (1 mm diameter, 50 mm long) placed in the world volume. Plastic material is VinylToluene with mass fraction of Carbon and Hydrogen 0.915 and 0.085,respectively. Density is 1.032*g/cm3.
- Physics list: Modular physics list - G4EmLivermorePolarizedPhysics
- Make a working Geant4 application and visualize. On visualizing, the detector should be visible similar to the below image.

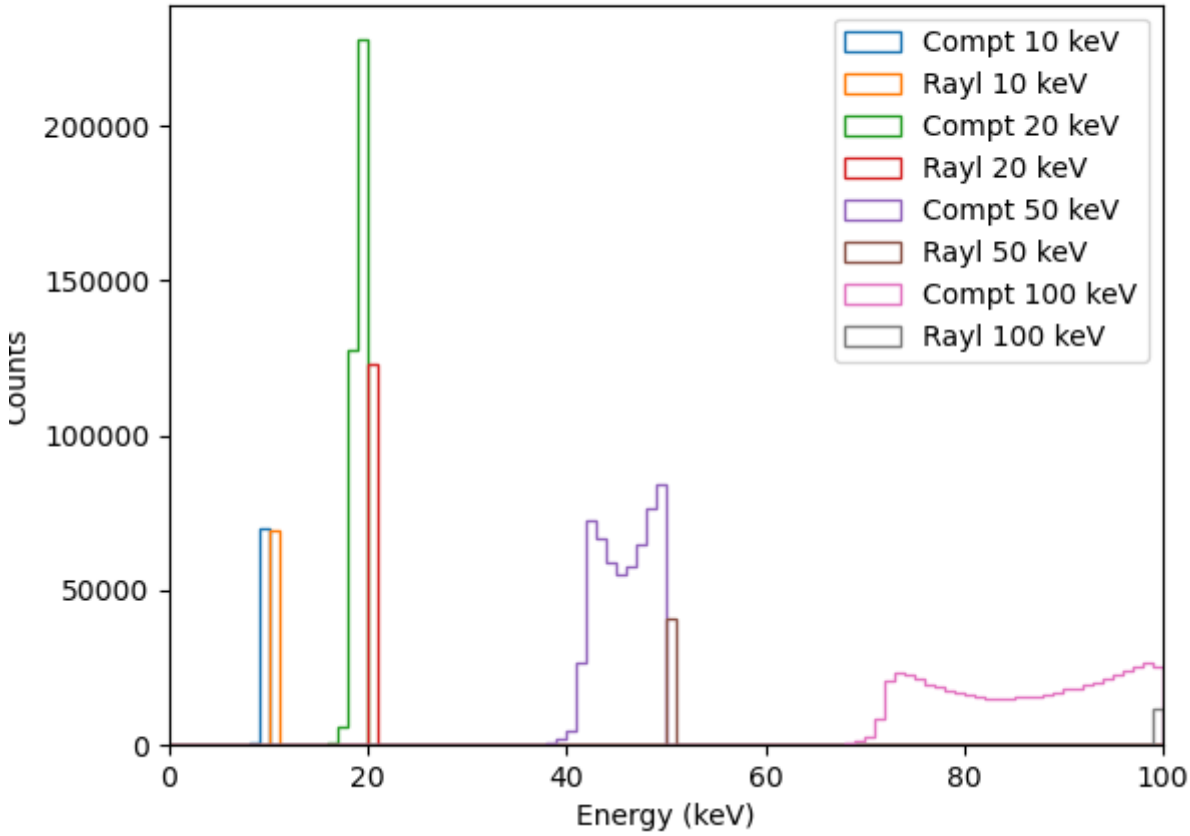


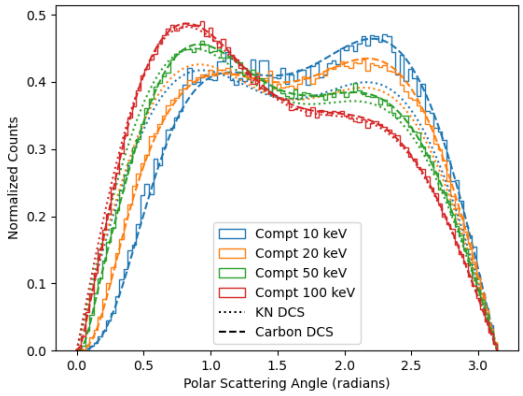
(**b**) Now, setup primary particles for simulation using General Particle Source (GPS). Place a source emitting mono-energetic parallel gammas in front of the scintillator. Run the simulation with this source with tracking verbose set to 1. You should see gammas interacting with scintillator as shown in the below image. Look at the verbose output and see the different processes that the primary gammas undergo in the detector.

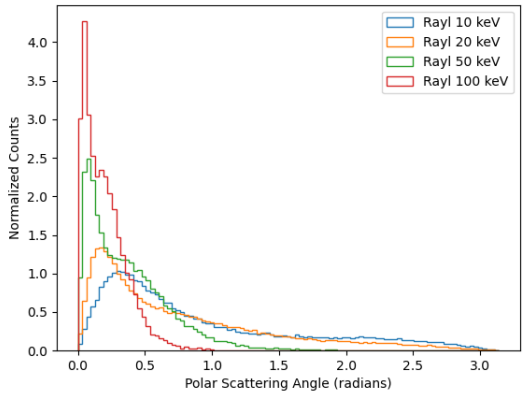


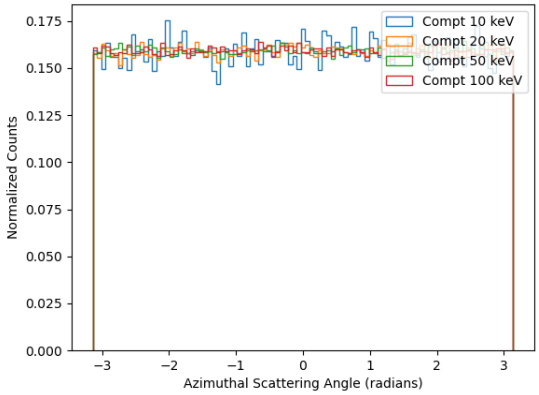
(**c**) By accessing the step point information using user stepping action, identify events undergoing rayleigh and compton scattering in the detector and record the scattered photon energy as well as the direction (Hint: Post-step point momentum). Note that we want to get only the first interaction of the primary gamma. For each primary event with scattering interaction, write out whether it was rayleigh or compton as well as the scattered photon energy and direction. Save the results in output text/root file.

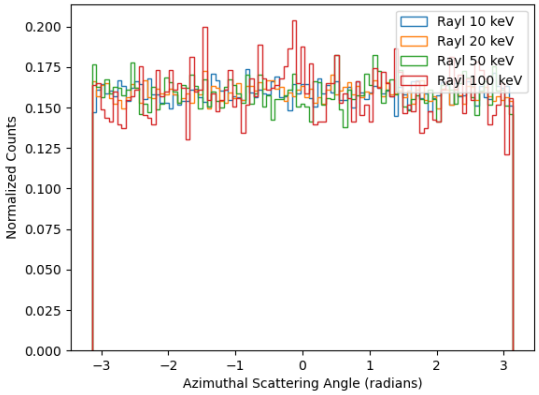
(**d**) Carry out simulations with 10 keV, 20 keV, 50 keV, and 100 keV photons and using the outputs from Geant4, plot the spectra of scattered photons (energy vs counts), histogram of scattering angle theta, and histogram of azimuthal angle phi as shown in the examples below. Try overplotting Klein–Nishina differential cross section of Compton scattering by free electrons with the distribution of polar angles obtained from Geant4 simulations.


Compt 10 keV
Rayl 10 keV
Compt 20 keV
Rayl 20 keV
Compt 50 keV
Rayl 50 keV
Compt 100 keV
Rayl 100 keV
Counts
Energy (keV)

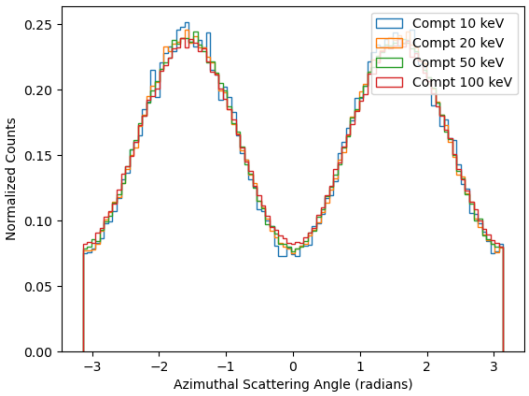

Compt 10 keV
Compt 20 keV
Compt 50 keV
Compt 100 keV
KN DCS
Carbon DCS
Normalized Counts
Polar Scattering Angle (radians)

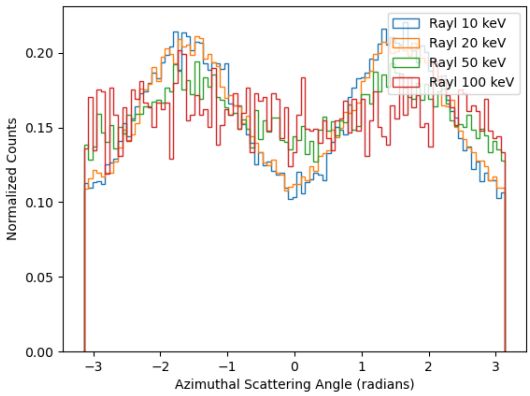

Rayl 10 keV
Rayl 20 keV
Rayl 50 keV
Rayl 100 keV
Normalized Counts
Polar Scattering Angle (radians)


Compt 10 keV
Compt 20 keV
Compt 50 keV
Compt 100 keV
Normalized Counts
Azimuthal Scattering Angle (radians)


Rayl 10 keV
Rayl 20 keV
Rayl 50 keV
Rayl 100 keV
Normalized Counts
Azimuthal Scattering Angle (radians)

(**e**) Repeat the above exercise with the same setup, but with the incident photons polarized in specific direction. Plot the different distributions as above. Note the difference in azimuthal scattering angle distributions as shown in figures below compared to that of unpolarized photons. See how the distribution varies with different polarization directions.



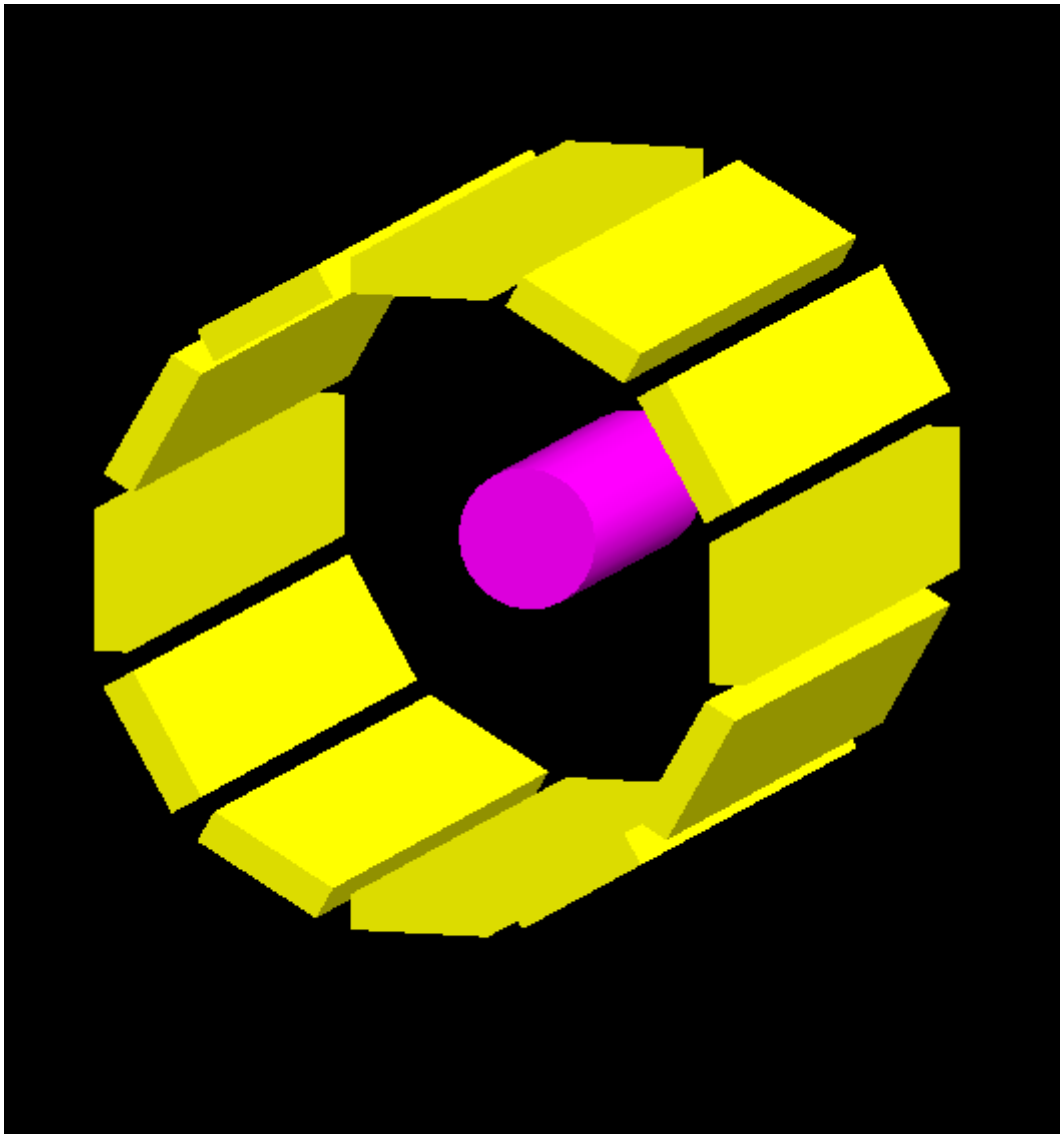


(**f**) Additional excercise: Have a look at how the azimuthal angle distribution for polarized photons vary when only photons of a selected range of theta values are considered, for example only between 60 to 120 degree. See how it compares with the azimuthal angle distribution for entire range of theta values.

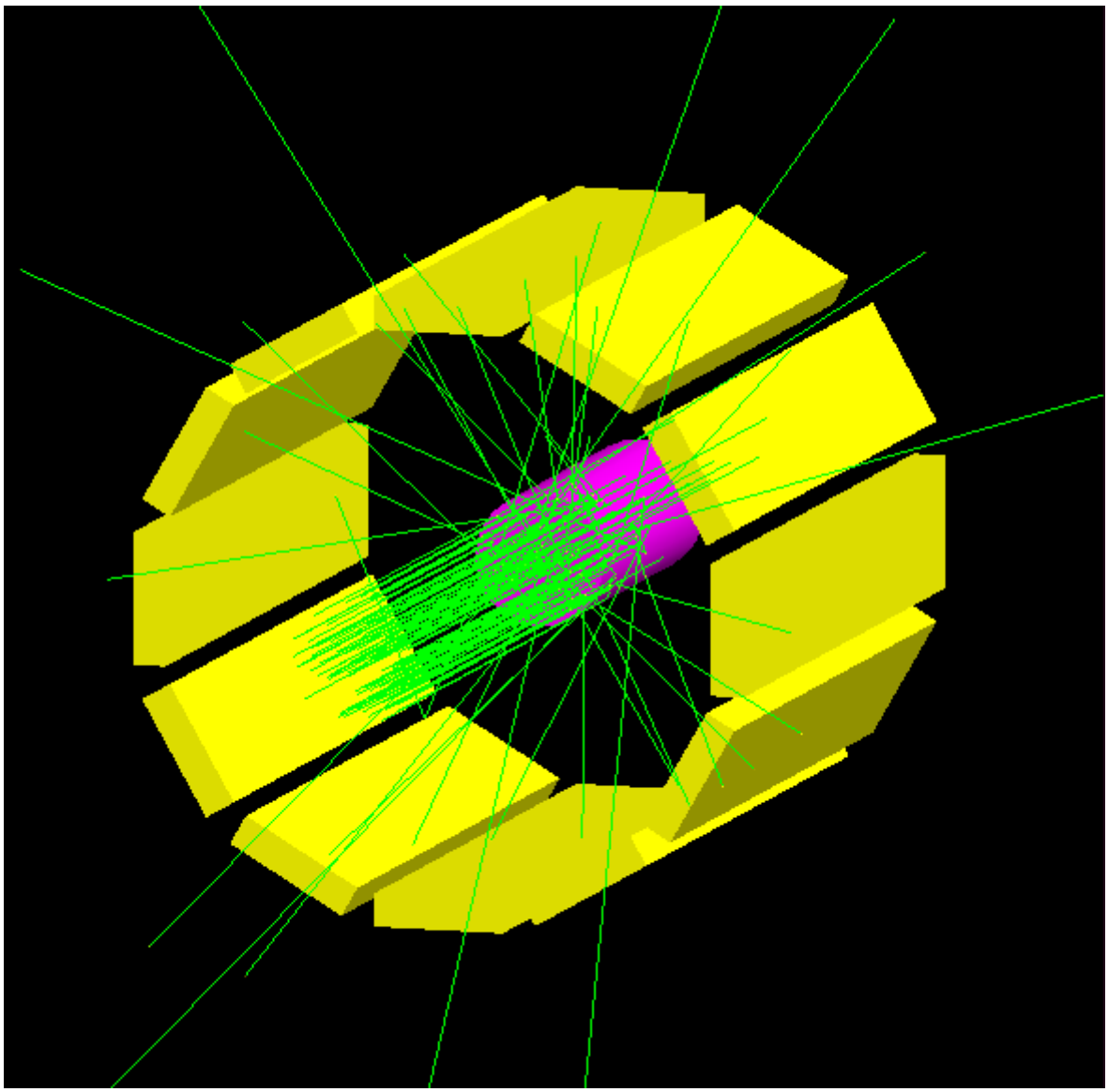
Problem 2: X-ray polarimeter simualtions

From the above excercise, we understand that the azimuthal scattering angle distribution is dependent on the polarization characteristics of the incident beam. So, if we manage to measure the the azimuthal angle distribution of the scattered photons, we can measure the polarization of the incident beam, which is how scattering X-ray polarimeters work.

So, let us do simulations of a simple ideal polarimeter as shown in the image below. At the center is a plastic scintillator as we used in earlier step, but with diameter of 20 mm and it is surrounded by 12 CsI(Tl) detectors of dimensions 100 mm x 20 mm x 5 mm. CsI(Tl) consists of 51.0549% Cs, 48.0451% I, and 0.9% Tl by mass with a density of 4.51*g/cm3.

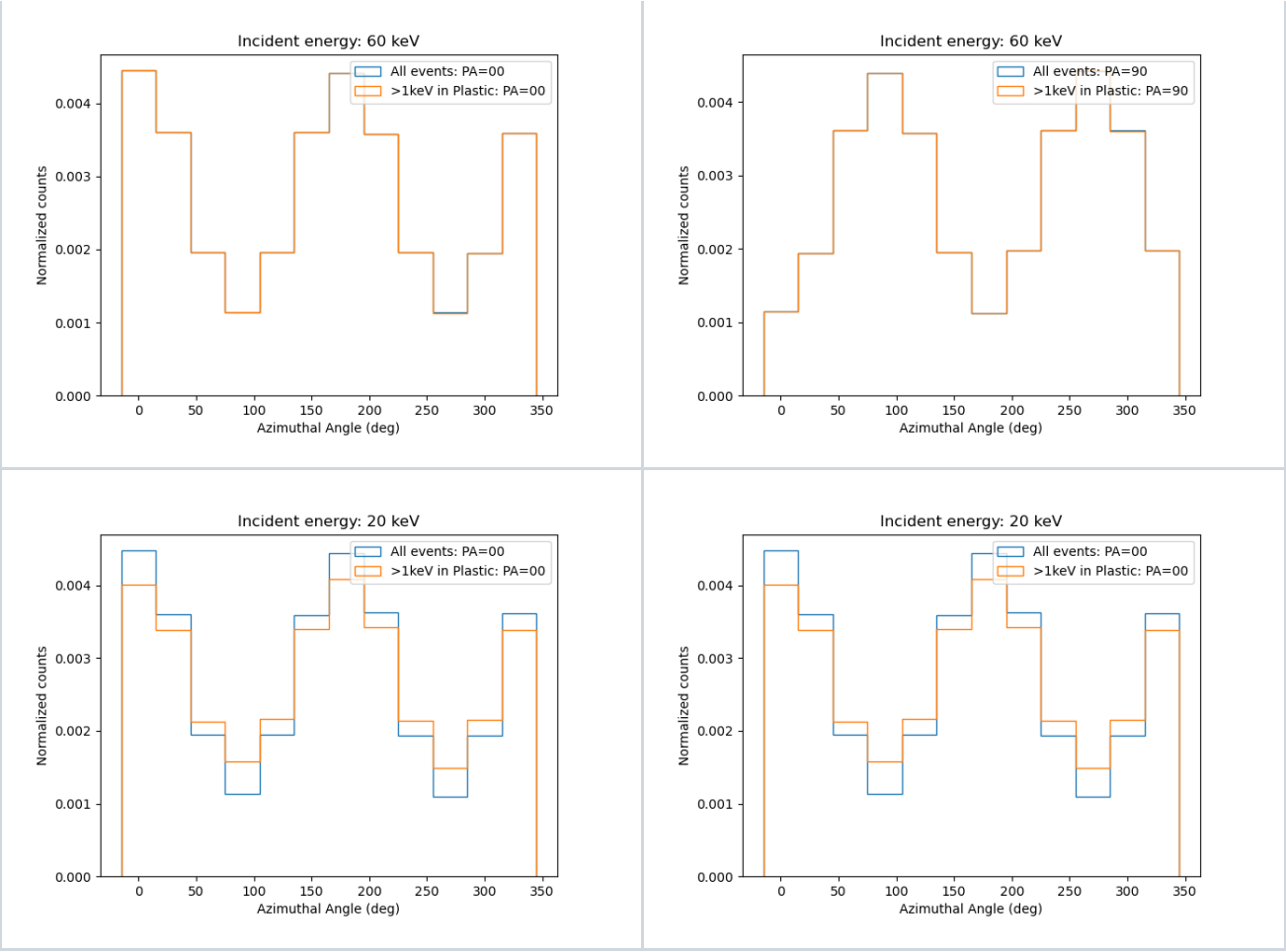


(**a**) Setup the above polarimeter geometry in Geant4. Using GPS, place a mono-energetic parallel gamma source in front of the platsic scintillator to run the simulations like shown in image below.



(**b**) For each event, using the scoring method of choice, record the energy deposition in plastic scintillator and each surrounding CsI detectors. For events having energy deposition in only one of the CsI detectors with/without any energy deposition in plastic, write out the CsI detector number as well as the energy depositions.

(**c**) Carry out simulations with polarized (and unpolarized) photons of different energies and plot histogram of the azimuthal angle distributions obtained from the CsI detector numbers. See what happens when conditions of minimum energy deposition in plastic is considered for event selection. Some representative plots are given below.



(**d**) Additional exercise: Try re-running the simulation with different diameters of the plastic scintilator and see how it affects the modulations seen in the azimuthal angle distributions.