Compton Scattering, experiment 4

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Overview

1. Experimental set-up
2. Calibrating zero
3. Energy calibration
4. Compton scattering formula
5. Differential cross section

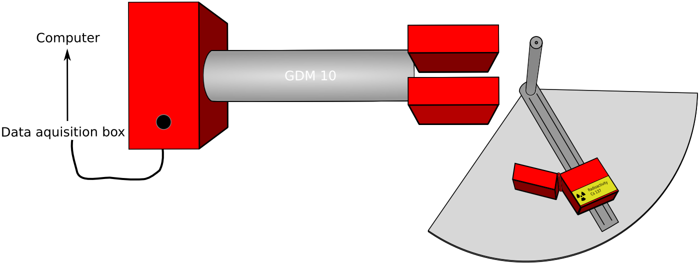


Figure (1) Set-up of our experiment

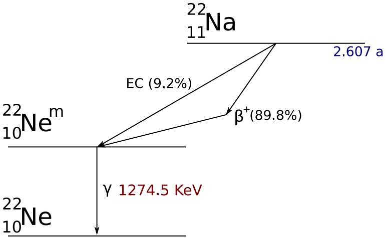


Figure (2) Caption

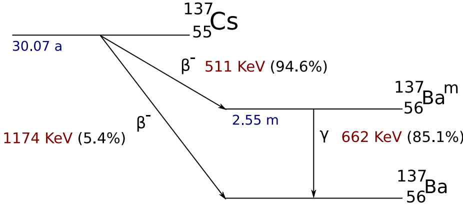
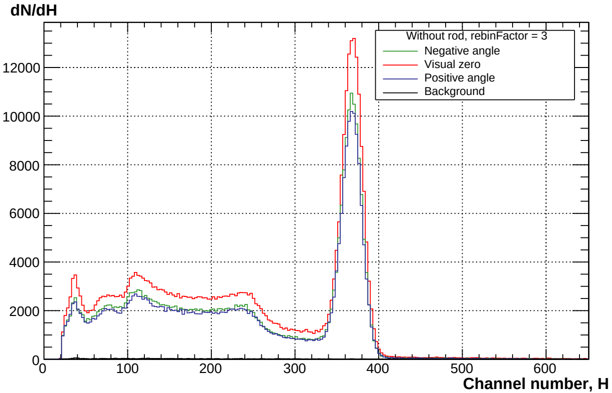


Figure (3) Caption



At the true zero mark, one would expect to see a decrease in the number of counts when adjusting the protractor either to the left or right. Since this is what we see in the above plot, we take the visual zero to be the true zero mark from here on. The true zero should be located at a slightly higher angle than the visual zero

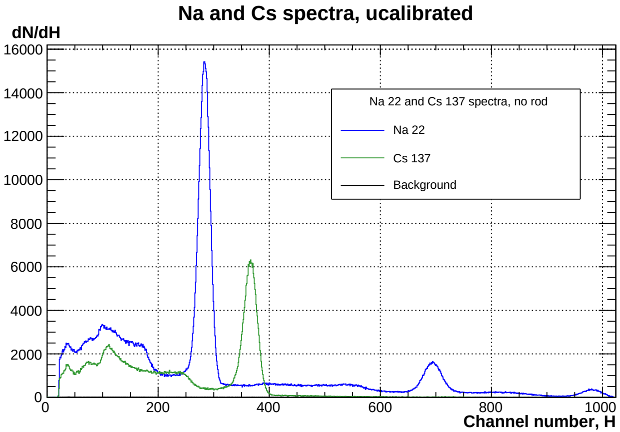

Na and Cs spectra, ucalibrated
dN/dH
16000
14000
12000
10000
8000
6000
4000
2000
0
0
200
400
600
800
1000
Channel number, H
Na 22 and Cs 137 spectra, no rod
Na 22
Cs 137
Background

Figure (4)

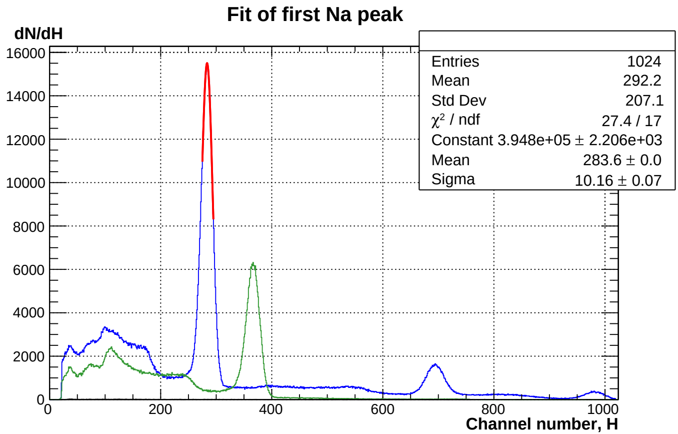


Figure (5)

- $H_0 = 283.6$

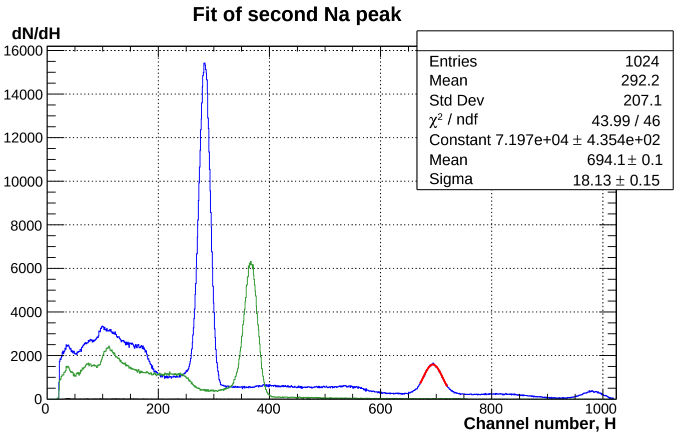


Figure (6)

- $H_1 = 694.1$

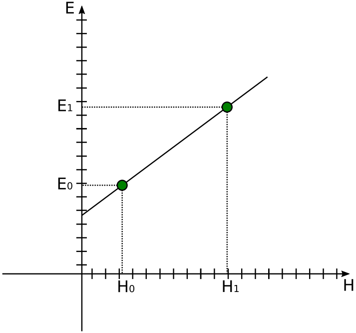


Figure (7) $\mathrm{E(H)} = \mathrm{E}_0 + \frac{\Delta E}{\Delta H} H = \textit{offset} + \textit{gain} * H$

E_0 and E_1 are found from the decay diagrams in the lab manual to be

- $E_0 = 511\,\mathrm{keV}$
- $E_1 = 1274.5\,\mathrm{keV}$

Thus giving us a gain of $\textit{gain} = (E_1 - E_0)/(H_1 - H_0) = 1.86\,\mathrm{keV}$
and an offset of $\textit{offset} = E_1 - \textit{gain} * H_1 = -16.48\,\mathrm{keV}$
Using this, we can now calibrate our spectra

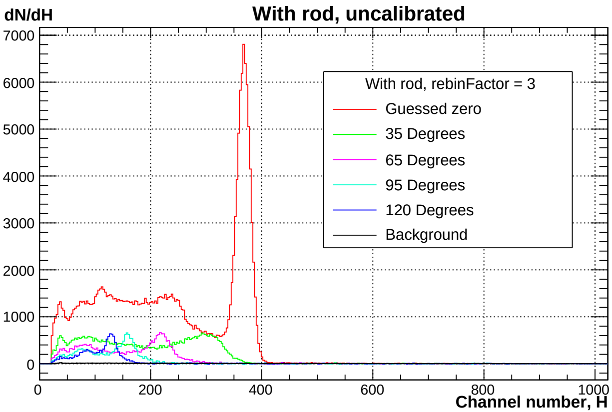

dN/dH
With rod, uncalibrated
7000
6000
5000
4000
3000
2000
1000
0
0
200
400
600
800
1000
Channel number, H
With rod, rebinFactor = 3
Guessed zero
35 Degrees
65 Degrees
95 Degrees
120 Degrees
Background

Figure (8)

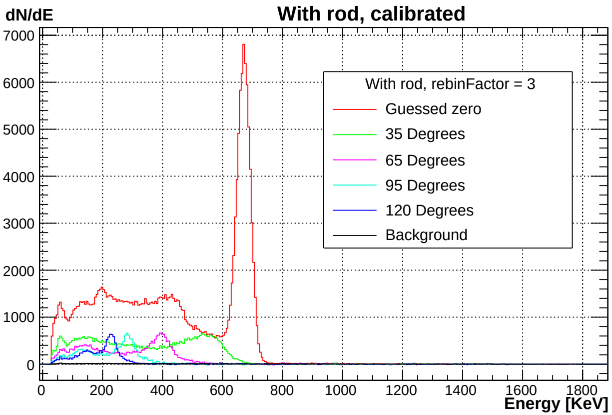

With rod, calibrated
dN/dE
7000
6000
5000
4000
3000
2000
1000
0
0
200
400
600
800
1000
1200
1400
1600
1800
Energy [KeV]
With rod, rebinFactor = 3
Guessed zero
35 Degrees
65 Degrees
95 Degrees
120 Degrees
Background

Figure (9)

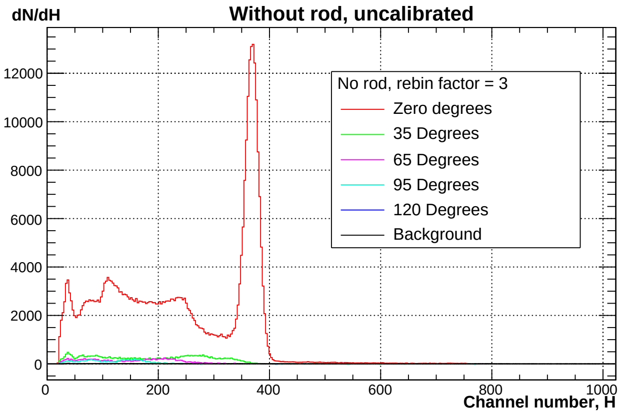
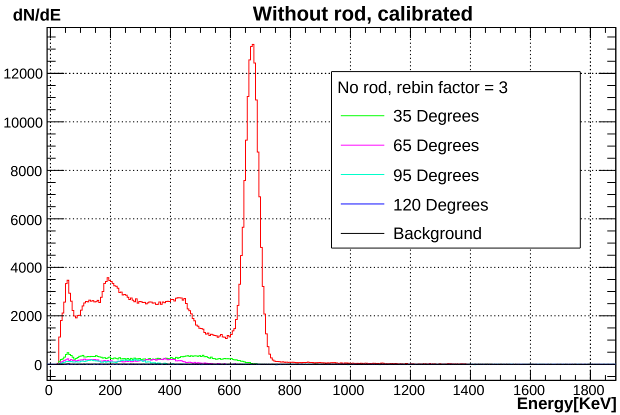

dN/dH
Without rod, uncalibrated
No rod, rebin factor = 3
Zero degrees
35 Degrees
65 Degrees
95 Degrees
120 Degrees
Background
0
2000
4000
6000
8000
10000
12000
0
200
400
600
800
1000
Channel number, H

Figure (10)



dN/dE
Without rod, calibrated
No rod, rebin factor = 3
35 Degrees
65 Degrees
95 Degrees
120 Degrees
Background
0
2000
4000
6000
8000
10000
12000
0
200
400
600
800
1000
1200
1400
1600
1800
Energy[KeV]

Figure (11)

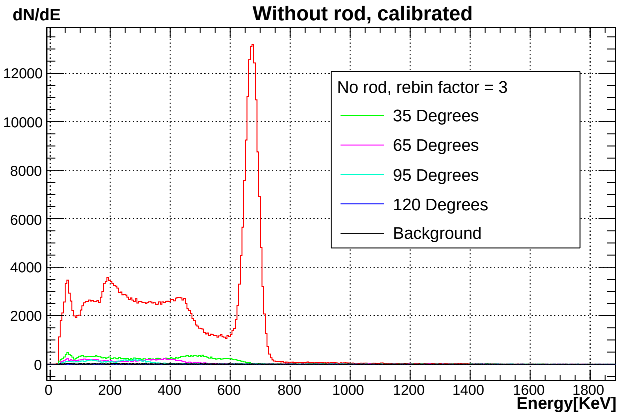


Figure (12)

As seen, there is still a small contribution even without the rod, indicating that the gamma rays must penetrate the steel shielding.

Removing the 0-degree graph reveals Compton continua, which likely are produced by photons going through the first shield and Compton scattering off the second, or Compton scattering off the first shield directly into the detector.

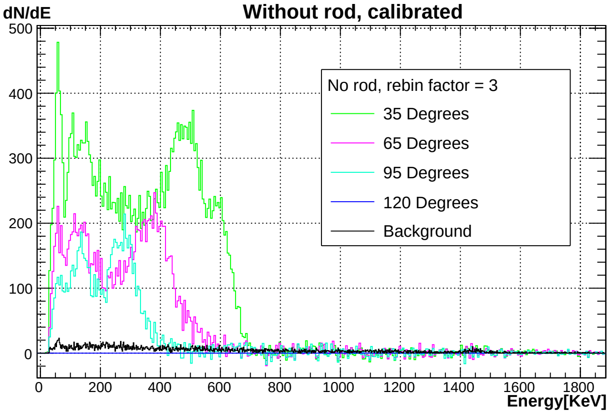
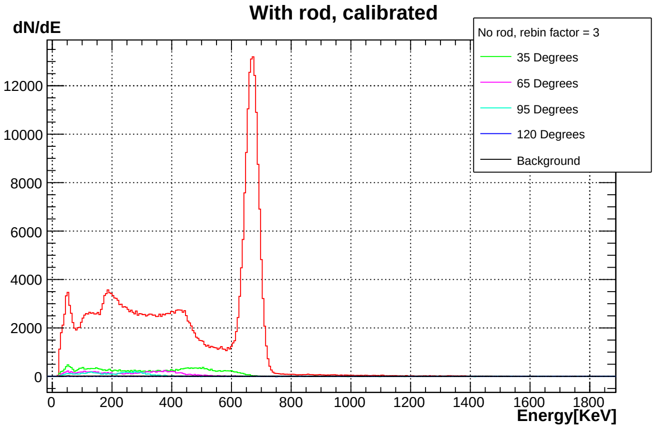


Figure (13)



With rod, calibrated
dN/dE
No rod, rebin factor = 3
35 Degrees
65 Degrees
95 Degrees
120 Degrees
Background
12000
10000
8000
6000
4000
2000
0
0
200
400
600
800
1000
1200
1400
1600
1800
Energy[KeV]

Figure (14)

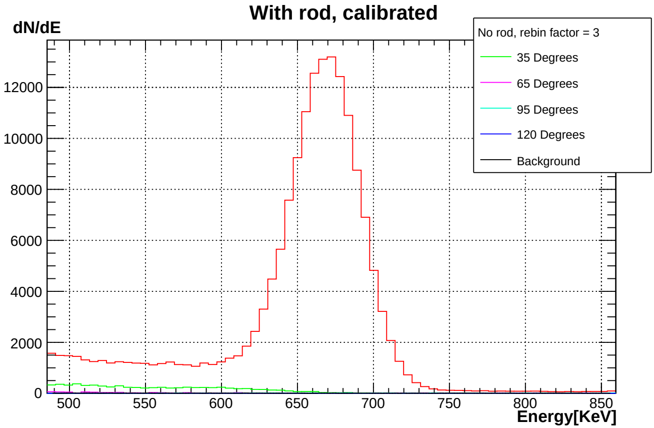

With rod, calibrated
dN/dE
No rod, rebin factor = 3
35 Degrees
65 Degrees
95 Degrees
120 Degrees
Background
0
2000
4000
6000
8000
10000
12000
500
550
600
650
700
750
800
850
Energy[KeV]

Figure (15)

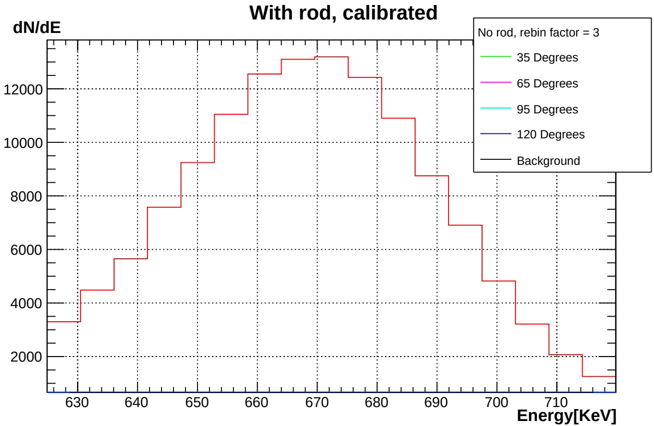

With rod, calibrated
dN/dE
No rod, rebin factor = 3
35 Degrees
65 Degrees
95 Degrees
120 Degrees
Background
12000
10000
8000
6000
4000
2000
630
640
650
660
670
680
690
700
710
Energy[KeV]

Figure (16)

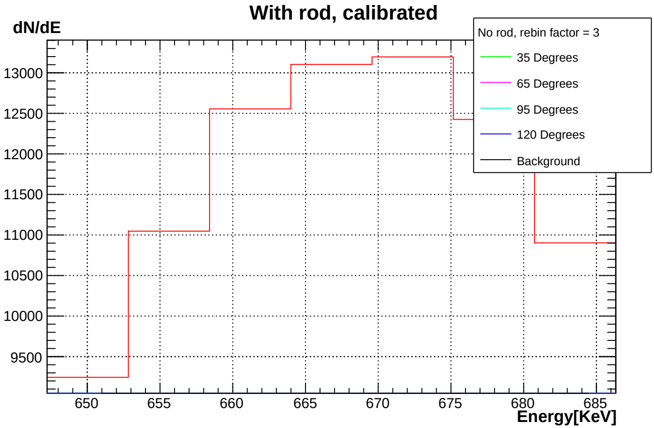
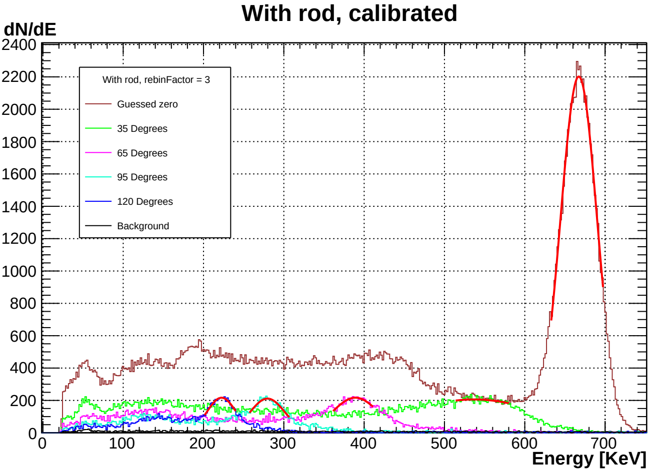

With rod, calibrated
dN/dE
No rod, rebin factor = 3
35 Degrees
65 Degrees
95 Degrees
120 Degrees
Background
13000
12500
12000
11500
11000
10500
10000
9500
650
655
660
665
670
675
680
685
Energy[KeV]

Figure (17)

As seen, The peak is doesn't quite land on 661.7 KeV. This might be due to uncertainties in our calibration coefficients stemming from fitting, which could be reduced by using three peaks rather than one, i.e. including the Cesium peak when calibrating. Furthermore, the peak is actually Poisson distributed. In the limit of $\lambda \to \infty$, it becomes Gaussian distributed. Thus the peak is only approximately Gaussian distributed, however the approximation becomes better for larger data sets (viz. longer data acquisition periods).



	Guessed 0°	35° − 6.57°	65° − 6.57°	95° − 6.57°	120° − 6.57°
Mean [KeV]	667.24 ± 0.13	536.88 ± 7.19	389.09 ± 23.6	279.09 ± 0.54	222.43 ± 0.53

Table (1) Fit results of the compton scattered peaks

	Guessed 0°	$35^\circ - 6.57^\circ$	$65^\circ - 6.57^\circ$	$95^\circ - 6.57^\circ$	$120^\circ - 6.57^\circ$
Mean [KeV]	667.24 ± 0.13	536.88 ± 7.19	389.09 ± 23.6	279.09 ± 0.54	222.43 ± 0.53

Table (2) Fit results of the compton scattered peaks

Here we see a scatter plot of the above table together with the blue line, which are the theoretical values given by

$$E_f = \frac{E_i}{1 + \frac{E_i}{E_r}(1 - \cos\theta)} \qquad (1)$$

With $E_i = 661.7\,\text{keV}$

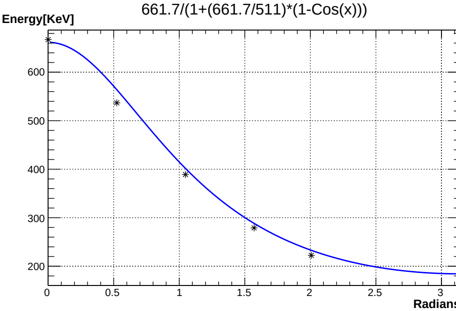


Figure (18)

Next, we do a fit to these data points and set E_r (the rest mass of the electron in NU) and E_i (the incident photon energy) as our fit parameters.

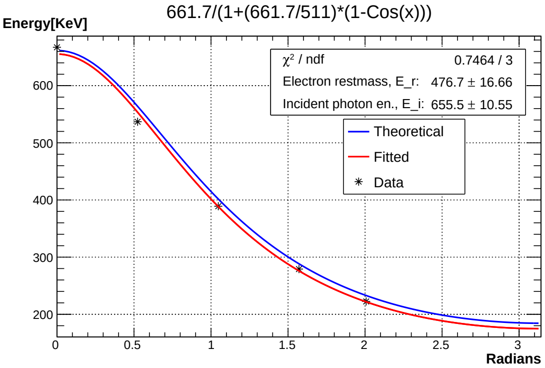


Figure (19)

- $E_r = 476.7\,\text{keV} \pm 16.7\,\text{keV}$ and
- $E_i = 655.5\,\text{keV} \pm 10.6\,\text{keV}$.

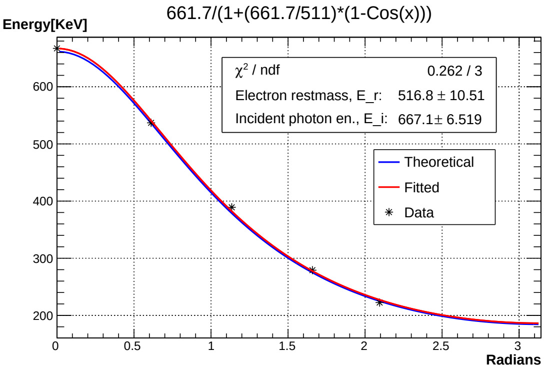

661.7/(1+(661.7/511)*(1-Cos(x)))
Energy[KeV]
χ^2 / ndf 0.262 / 3
Electron restmass, E_r: 516.8 ± 10.51
Incident photon en., E_i: 667.1± 6.519
Theoretical
Fitted
Data
600
500
400
300
200
0
0.5
1
1.5
2
2.5
3
Radians

Figure (20)

- The 511 keV stems from $\beta+$ radiation emitting a positron which promptly annihilates with an electron, producing two gamma rays of energy 511 keV each. The detector then detects one of these gamma rays

The differential cross section as a function of θ is given by

$$g(\theta) = \pi r_0^2 \left(\frac{E_f}{E_i}\right)^2 \left(\frac{E_f}{E_i} + \frac{E_i}{E_f} - \sin^2\theta\right) \sin^t heta \tag{2}$$

Where $E_i = 661.7$ KeV and

$$E_f = \frac{E_i}{1 + \frac{E_i}{E_r}(1 - \cos\theta)} \tag{3}$$

It can be thought of as the probability of scattering into a ring at a given angle θ of infinitesimal width, as illustrated in the figure below

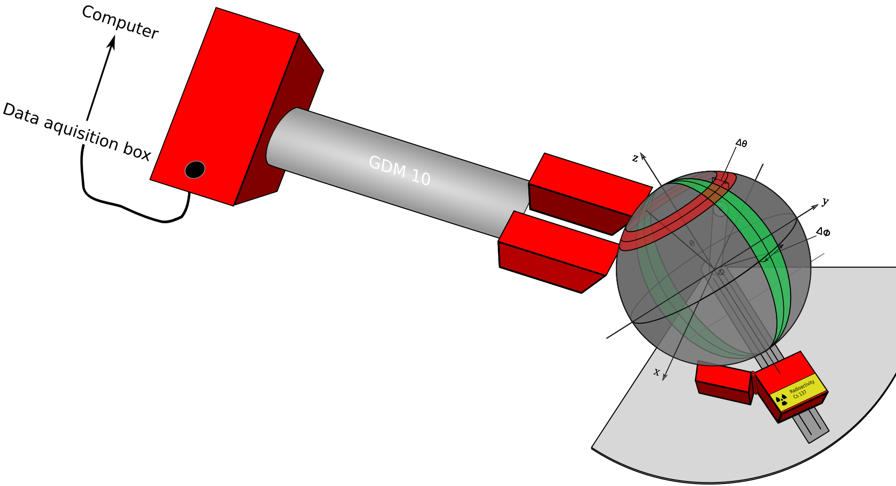


Figure (21) Caption

The rate at which we detect radiation, $\frac{dN}{dt}$, should therefore depend on the scattering angle. Furthermore, we have

$$N(t_{aq}, \theta) = \frac{dN}{dt}(\theta) * t_{aq} \tag{4}$$

$$\Rightarrow \frac{dN}{dt}(\theta) = \frac{N(t_{aq}, \theta)}{t_{aq}} \tag{5}$$

We found the total count at a given angle, $N(t_{aq}, \theta)$, by subtracting the spectrum at this angle without the rod from the spectrum at the same angle with the rod and summing all the bin counts of this subtracted spectrum.

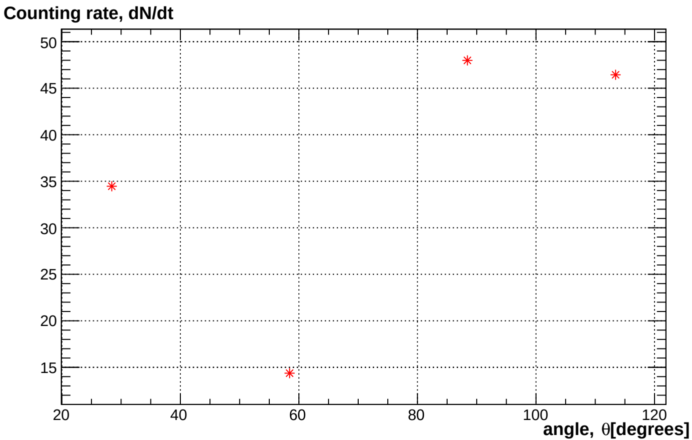


Figure (22) Caption

The differential cross section for the recoil electron is given by

$$\frac{d\sigma}{dE_k} = 2\pi m_e c^2 r_0^2 g(\theta) \frac{\left[1 + \frac{E_i}{m_e c^2}(1 - \cos\theta)\right]^2}{E_i^2} \tag{6}$$

With

$$g(\theta) = \frac{1}{2}\left(\frac{E_f}{E_i}\right)^2 \left(\frac{E_f}{E_i} + \frac{E_i}{E_f} - \sin^2\theta\right) \tag{7}$$

We can plot this differential cross section as a function of θ:

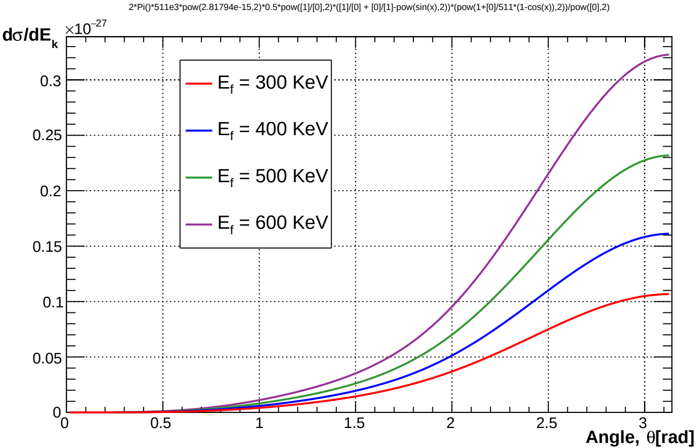


Figure (23) Caption

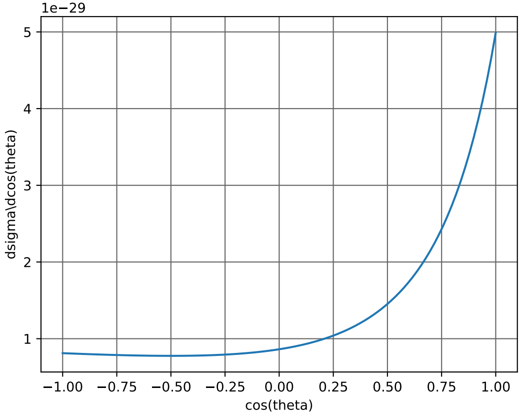


Figure (24) Caption