Feasibility of Using Cd-109 as a Calibration Source For CRES

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Abstract

The journey to search for appropriate sources to calibrate the CRES instrument is challenging, but Cadmium-109 (Cd-109) has emerged as a promising solution due to its suitable decay spectrum (convenient lifetime about 461.4 days [1]), market availability [3] and compatibility with various detector types. To evaluate the feasibility of utilizing Cd-109 for instrument calibration, simulations of its decay products have been conducted, whose results were then used to confirm if Cd-109 meets the necessary criteria for effective and precise calibration.

1 Introduction

To evaluate the feasibility of using Cd-109 as the primary calibration source for CRES instrument, it is essential to examine its energy spectra for a distinct peak abound 18.6 keV, which is close to the endpoint for tritium. According to Table 1, experimental decay pattern for Cd-109 should give a distinct peak around 18.5 keV. Within the decaying stimulation, the Cd-109 source is configured into two geometries, QSA and Isotrak, both charaterized by a pancake shape based on commercial sources and surrounded by additional material. Additionally, two newly defined geometries, Point-like and Shell, are considered in the following section. These are "idealised" source geometry if we are making our own sources.

2 Geometry of the Source

The geometry of the source could vastly influence energy spectra of the source. Therefore, comparison needs to be made among produced energy spectra in different geometries in order to select the best fit geometry for calibration.

2.1 QSA

The QSA source geometry is defined by a Cd-109 surface deposited on a Nickel backing, covered by an Acrylic window of a thickness of (100-200) μm, the radius of the Cd-109 source is 5 mm with the thickness of Nickel backing undefined. The simulated energy spectra in 100k events is shown in Figure 3. According to the plot, large tails are clear amongst the spectra while around the targeted value, 18.6 keV, there is no significant peak observed. Therefore, QSA does not seem to be the suitable geometry for the calibration source.

2.2 Isotrak

As to the Isotrak geometry, it is defined by a Cd-109 column emitter layer sandwiched between two Mylar foils. The thickness for the Cd-109 source is 100 nm and for two Mylar foils are 0.9 mg/cm^2. The energy

Electrons:

	Energy (keV)	Intensity (%)	Dose (MeV/Bq-s)
Auger L	2.61	167.3 % *9*	0.004367 *24*
Auger K	18.5	20.8 % *5*	0.00385 *9*
CE K	62.5196 *10*	41.8 % *8*	0.0261 *5*
CE L	84.2278 *10*	44.2 % *9*	0.0372 *8*
CE M	87.3161 *10*	9.05 % *20*	0.00790 *17*
CE N	87.9384 *10*	1.41 % *3*	0.00124 *3*

Gamma and X-ray radiation:

	Energy (keV)	Intensity (%)	Dose (MeV/Bq-s)
XR l	2.98	10.4 % *3*	3.09E-4 *8*
XR kα2	21.99	29.8 % *9*	0.00655 *19*
XR kα1	22.163	56.1 % *16*	0.0124 *4*
XR kβ3	24.912	4.80 % *14*	0.00120 *3*
XR kβ1	24.943	9.3 % *3*	0.00231 *7*
XR kβ2	25.455	2.31 % *6*	5.89E-4 *16*
	88.0336 *10*	3.644 % *16*	0.003208 *14*

Figure 1: Experimental data for the energies of electrons and gamma rays produced by the decaying Cadmium-109. [2]

spectra produced by the Isotrak source is illustrated in Figure 4. According to the plot, only the peaks at higher energies can be spotted. This may because the Mylar foils trapped most of the electrons at lower energies. In this case, Isotrak can not be the appropriate geometry used in calibration process due to lack of sharp peaks around 18.6 keV.

2.3 Point-like

Given the limitations of the pancake geometry, specially, the material (acrylic and Mylar) used to encapsulate the source, we propose an alternative approach utilizing a spherical geometry. Firstly, a point-like source was modelled as a solid sphere with a micron-scale radius, effectively representing a point source in three-dimension space. As can be seen from Figure 5, the shape of the energy spectra changes with the radius of the point-like source. The smaller the point-like source is, the smaller the width is for the peak around the target range of 18.6 keV, hence a better calibration precision for the calibration. In general, a singular sharp peak was observed at the target area with very small width for small radius, which proves that the point-like geometry is a good candidate for calibration.

2.4 Shell

Despite the previous success of the Point-like geometry for calibration, the difficulty in fabricating such a micron-scale radius source needs careful consideration. Therefore, a more feasible approach is to explore the shell symmetry, where a non-radioactive base sphere, made of aluminium in this case, is electro-deposited [4] with a thin layer of Cd-109. The specific distributions of kinetic energy, as displayed in Figure 6 and 7, exhibit sharp peaks at expected values with tails resulting from the interference of the solid aluminum sphere with the escaping electrons. Therefore, instead of using the difficult-to-fabricate point-like source, the shell source is more preferable since it is easier to produce and can generate useful energy spectra.

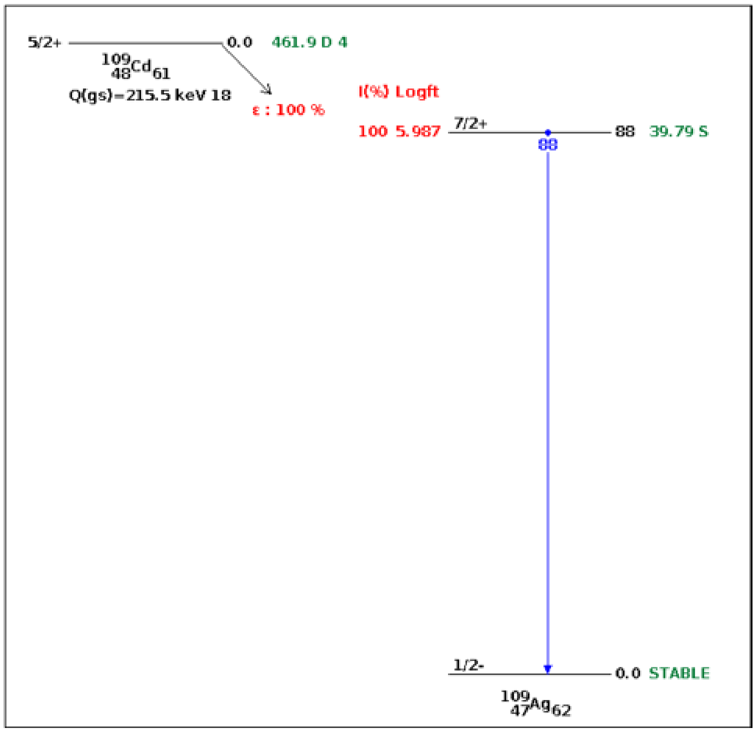


Figure 2: The decay scheme for Cd-109 [2]

3 Data Analysis of Shell Geometry

Based on the previous section's conclusion that shell symmetry is the most ideal, the feasibility of the Cd-109 source should be tested by analysing the energy spectra for this geometry. The key variables to consider are the radius of the aluminum sphere and the Cd-109 shell thickness.

3.1 Different Aluminum Sphere Radius

According to Figure 5 which illustrates the energy spectra for different sizes of aluminum spheres, the energy distribution indicates no dependence on the radius of the inner aluminum solid sphere. Therefore, a 50 μm radius of aluminum solid sphere is selected for the following part of analysis for different shell thicknesses.

3.2 Different Shell Thickness

To analyse the nonuniform distribution, a technique called kernel density estimation (kde) was applied to estimate the probability density function (PDF) of the electron energy.[5]

The plots in Figure 6 illustrate the energy spectra for varying the thickness (t) of the shell with a fixed radius for the base aluminum sphere. Around 18.6 keV, the widths of the peaks varies with different shell thicknesses. The precision of the calibration is directly linked to the width of the peak around the target area. The widths of peaks in this case are the width at a relative height of 0.8 height of the peaks. Figure 7 shows a clear linear correlation between the widths of the peaks and thickness of the Cd-109 shell, except for a noticeable drop of the width at t = 1000 μm. This is likely due to the shell being too thick, trapping outgoing electrons and causing a reduction in detected electron energy, which increases the width of the tail.

Additionally, as illustrated in Figure 9, the yields per 100k reduces along with the thickness and when the thickness increase to a certain point, the yields would be independent of thickness of the shell, which proves our assumption that thick shell traps outgoing electrons. Therefore, when the thickness is increased up to a certain value, only a fixed number of electrons can be detected at the scoring surface.

4 Discussion

The Cd-109 can be utilized in CRES instrument for several key purposes. The peak around 18.5 keV can be used to verify the functionality of CRES instrument and peaks in the other energies can be used to understand the linearity of the instrument. Additionally, higher peaks around 60-80 keV would be able to simulate the cases for the production of high-energy cyclotron radiation. But we have to assume the instrument has the sensitivity to detect lower frequency associated with higher energy. However, for high-precision energy calibration, Cd-109 may be unsuitable because the tail width abound the endpoint of tritium is in the keV range, which is too broad for a high precision energy calibration.

References

[1] National Isotope Development Center. (n.d.). Cadmium-109 Availability. Retrieved from https://www.isotopes.gov/node/311: :text=Most

[2] S. Kumar, J. Chen, and F.G. Kondev. ”Nuclear Data Sheets for A=109.” Nuclear Data Sheets, vol. 137, 2016, pp. 1. Available at: https://www.nndc.bnl.gov/nudat3/decaysearchdirect.jsp?nuc=109Cdunc=NDS

[3] H.T. Russell. ”Reactor Production of ^{109}Cd: Isotopic Composition and Use as an X-Ray Source.” Nuclear Applications, vol. 1, no. 2, 1965, pp. 151-154.

[4] J.E. C.-C., P.A.-P., and M.M.-H.I. González. ”Electrocrystallization of Cadmium on Anodically Formed Titanium Oxide.” Springer-Verlag Berlin Heidelberg, 2012.

[5] Chen, Y. C. (2017). A tutorial on kernel density estimation and recent advances. Biostatistics Epidemiology, 1(1), 161–187. https://doi.org/10.1080/24709360.2017.1396742

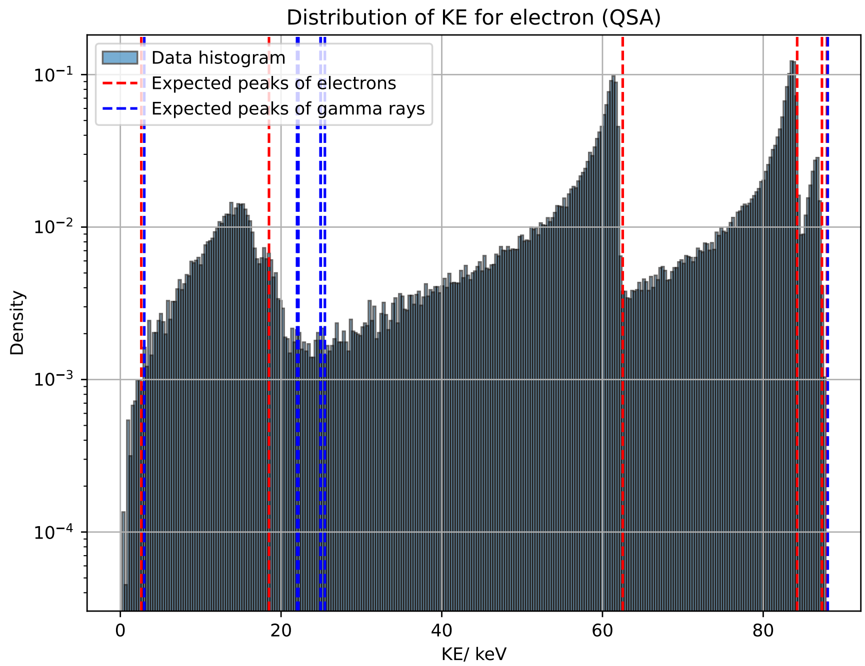


Figure 3: Simulated energy spectra of the QSA symmetry. The dashed vertical lines indicating the expected experimental energy peaks according to Figure 1.

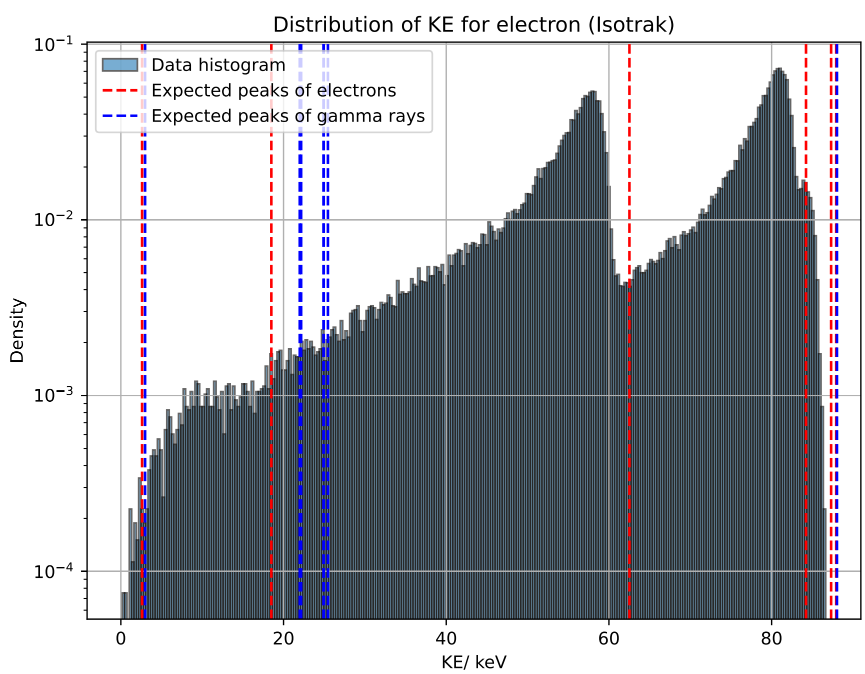
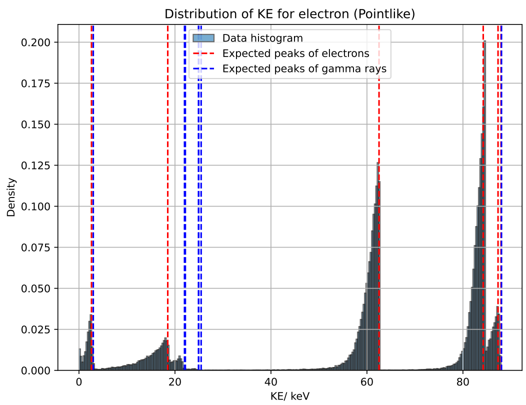
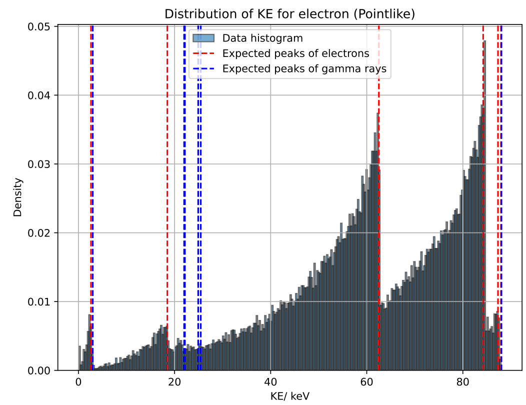


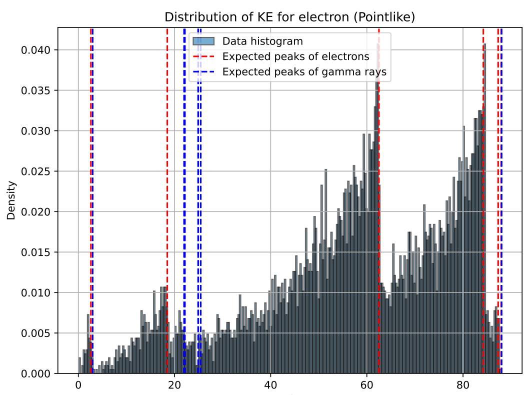
Figure 4: Simulated energy spectra of the Isotrak symmetry. The dashed vertical lines indicating the expected experimental energy peaks according to Figure 1.



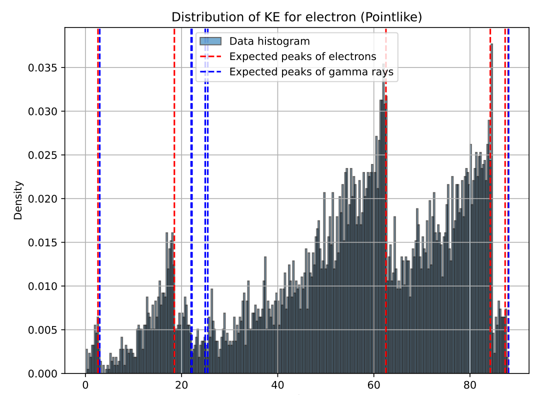
(a) r = 1 μm



(b) r = 10 μm

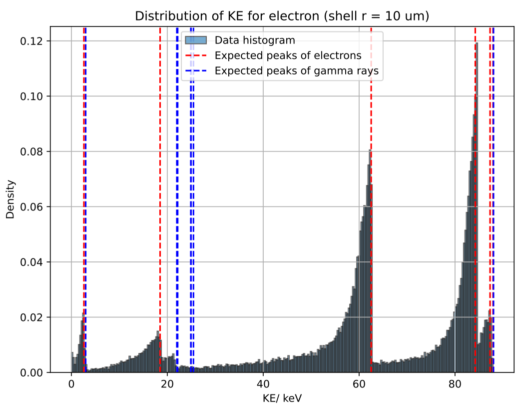


(c) r = 100 μm

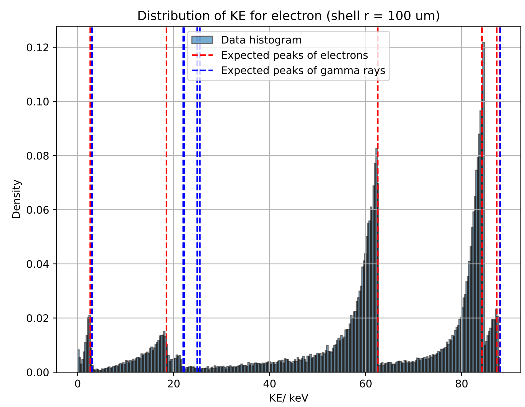


(d) r = 1000 μm

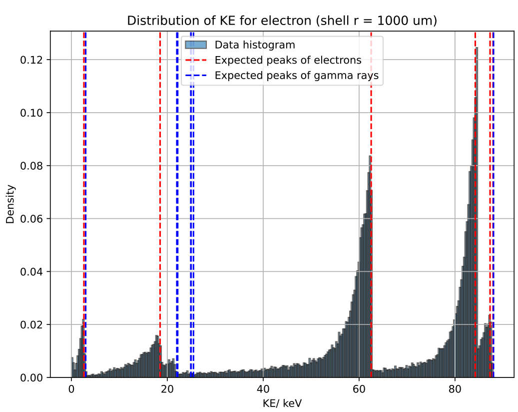
Figure 5: Energy spectra for Point-like geometry for spherical radius (r).



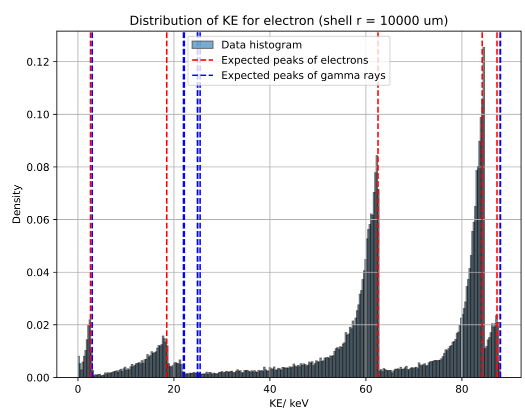
(a) r = 50 μm



(b) r = 100 μm

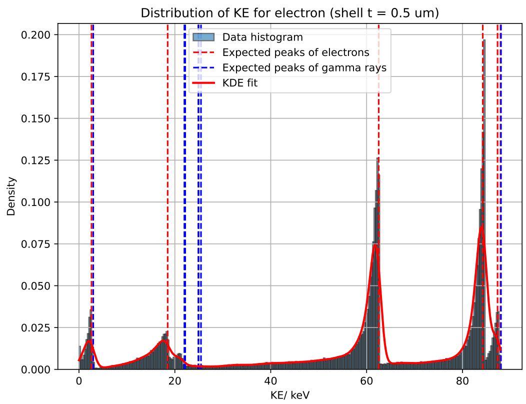


(c) r = 1000 μm

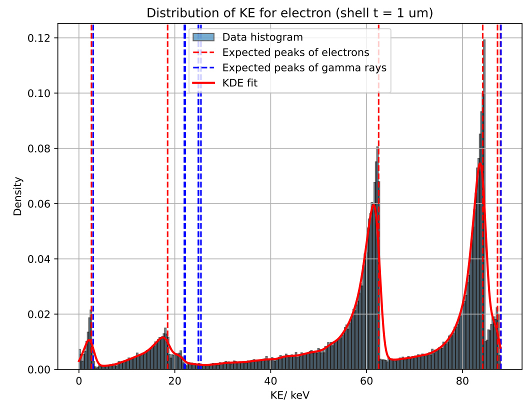


(d) r = 10000 μm

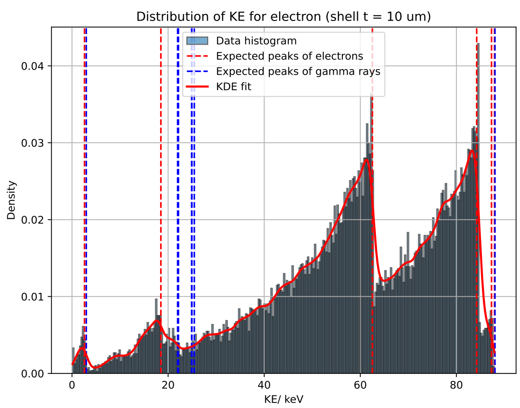
Figure 6: Energy spectra for shell geometry for different size of inner base solid sphere (r) with a fixed shell thickness (t = 1μm).



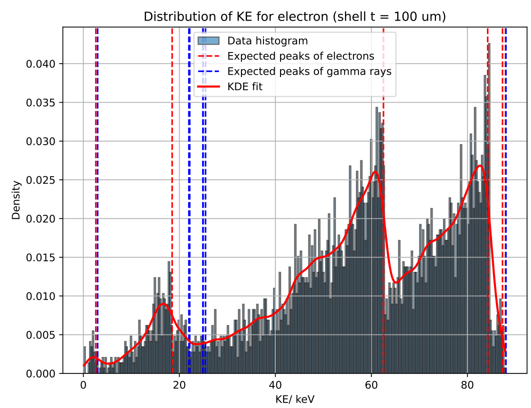
(a) r = 0.5 μm



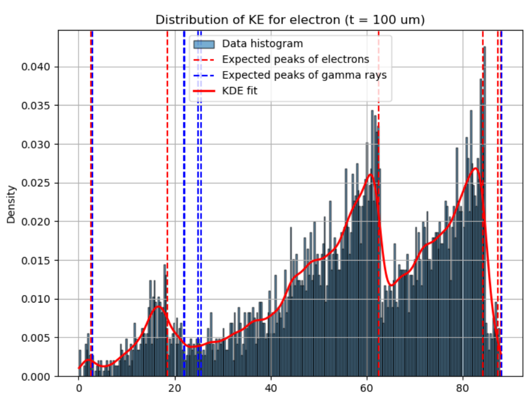
(b) r = 1 μm



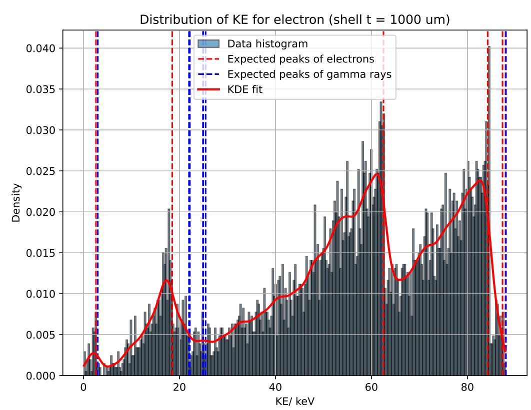
(c) t = 5 μm



(d) t = 10 μm



(e) t = 100 μm



(f) t = 1000 μm

Figure 7: Energy spectra with fitted kde for the shell geometry with inner sphere radius fixed (r = 50 μm) and different thickness (t).

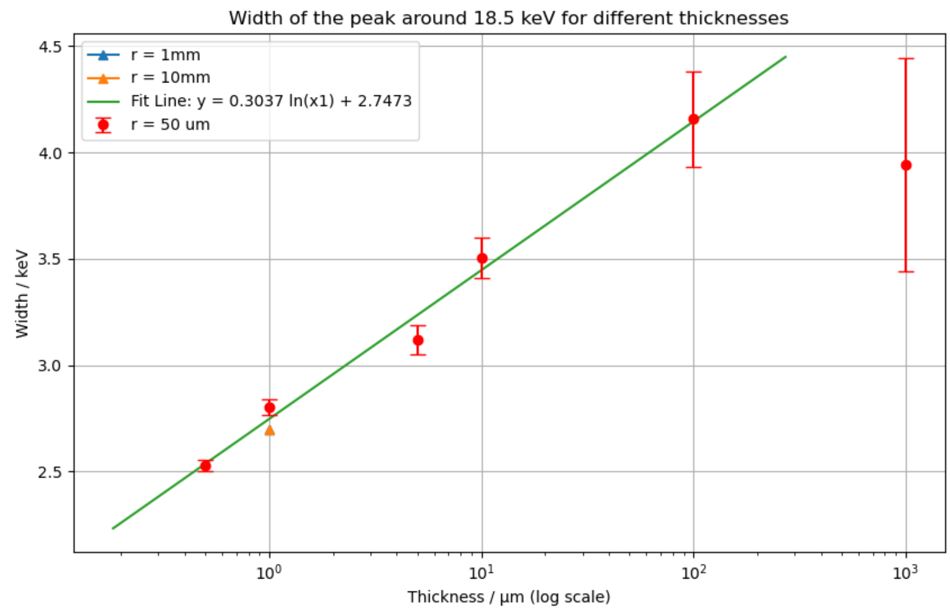


Figure 8: The dependence of width of peaks around 18.5 keV with the thickness of the shell, the size of the inner sphere is fixed with a radius r = 50 μm.

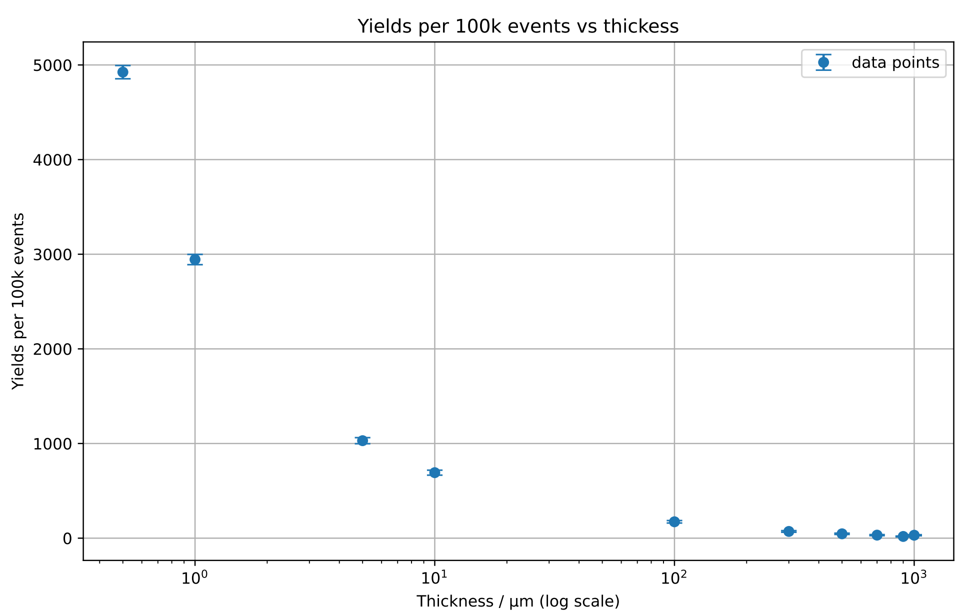


Figure 9: The correlation between thickness and yields per 100k events