Remote Gamma Cross Sections

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Introduction:

In the undergraduate lab, often times students will end up with results that are not close to the literature values, even with their estimated error. When this happens, it is easy to write this off as some kind of unexplained error. However, with enough time to study and test the apparatus, any kind of unknown uncertainty could be discovered and quantified. One such experiment affected by this unknown error is the first lab we performed: Gamma Cross Sections. This lab had many students' results which did not line up with literature values, and the students often attributed it to some unknown error without investigating what might be causing this error. Our goal for this experiment was to find out what could be some of the sources of this unknown error. This is important, as it helps us better understand the mechanics behind the experiment, and provides a way to refine the experiment so that we can have more accurate results. There are a few potential sources of error we investigated: the geometry of the apparatus and potential sources of centroid drifting.

Geometry:

The geometry of the setup features the source, a sodium iodide detector, and an aluminum absorber. They are oriented vertically as seen in the Figure 1 below. The geometry of the setup is important, as since we are dealing with a radioactive source, it emits gammas in a 360-degree sphere. All the gammas emitted in this sphere obviously won't hit the detector; only a certain conical section will.

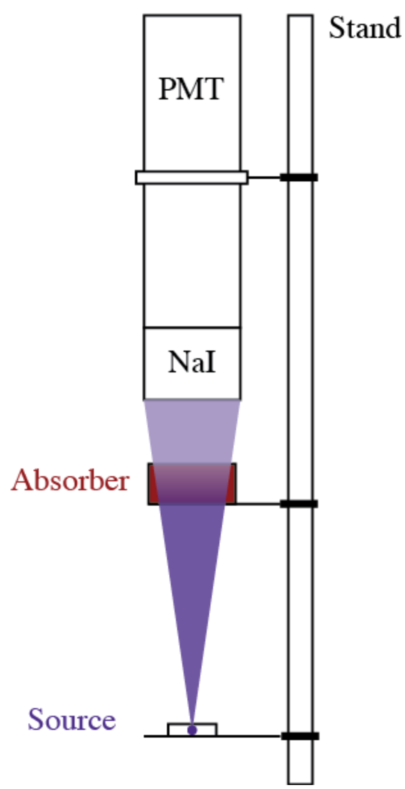

Figure 1: A sketch of the setup from the lab wiki. This is an example of "good geometry" as the absorber is the same size as the cone that would have hit the detector.

However, depending on the size and location of the absorber, some gammas that would have originally missed the detector may hit the absorber and scatter into the detector if the absorber is too close to the source. Additionally, if the absorber is too far from the source, some gammas may enter the detector without passing through the absorber. Both of these possible flaws would increase the count rate compared to some ideal “good geometry” where neither effect takes place. To help visualize, both situations are depicted below.

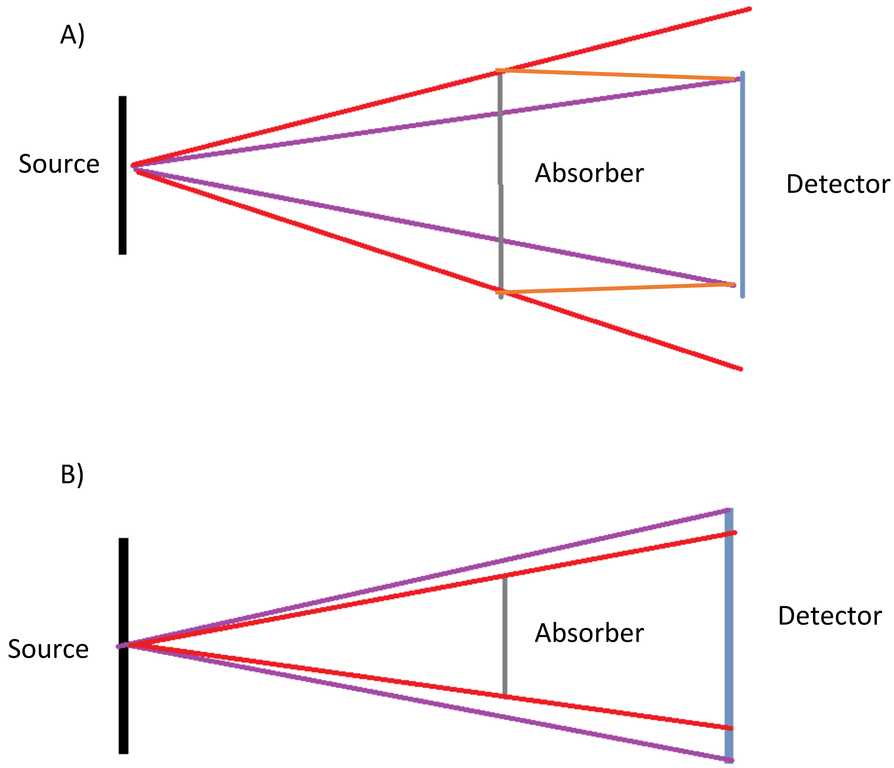

Figure 2: A figure showing the potential flaws in geometry

In the figure above, A) shows a detector that is too close to the source for its size, as the red cone, which represents the gammas that hit the absorber, is far greater than the purple cone, which represents the gammas that would have hit the absorber. This increases the count rate, as some of those more gammas may scatter into the detector as represented by the orange line. B) shows what happens if you have an absorber that is too close to the detector for its size. The absorber does not interact with all the gammas that will hit the detector letting some unattenuated gammas through. This would also cause an increase in count rate.

Therefore, we theorized that there is some hypothetical critical height where the absorber is only attenuating gammas that would have hit the detector. Since both flawed situations lead to an increase in count rates, the critical height we are looking for would be a minimum in count rate.

In order to look for this we recorded spectrums at varying height steps with the other variables (absorber thickness, gain, and the type of source) held constant. In order to get clean step divisions, we had the height steps be fractions of the total height of the apparatus (i.e 1/10, 2/10, … 9/10). We then would fit the peaks of this data to a gaussian and extract values from the fit. Upon receiving the data, we realized that the diameter of the absorber was larger than that of the detector, because of this, we expect to only have one of the aforementioned cases. We only expect the case in which the detector is too close (A), as it is impossible for the absorber to not cover the detector. Therefore, we expected to see a downward trend in the counts as we the absorber is moved closer to the detector.

Geometry in relation to Compton Scattering:

First, we looked at the 1.27 MeV peak of Na-22, as it had very little background making the data clearer.

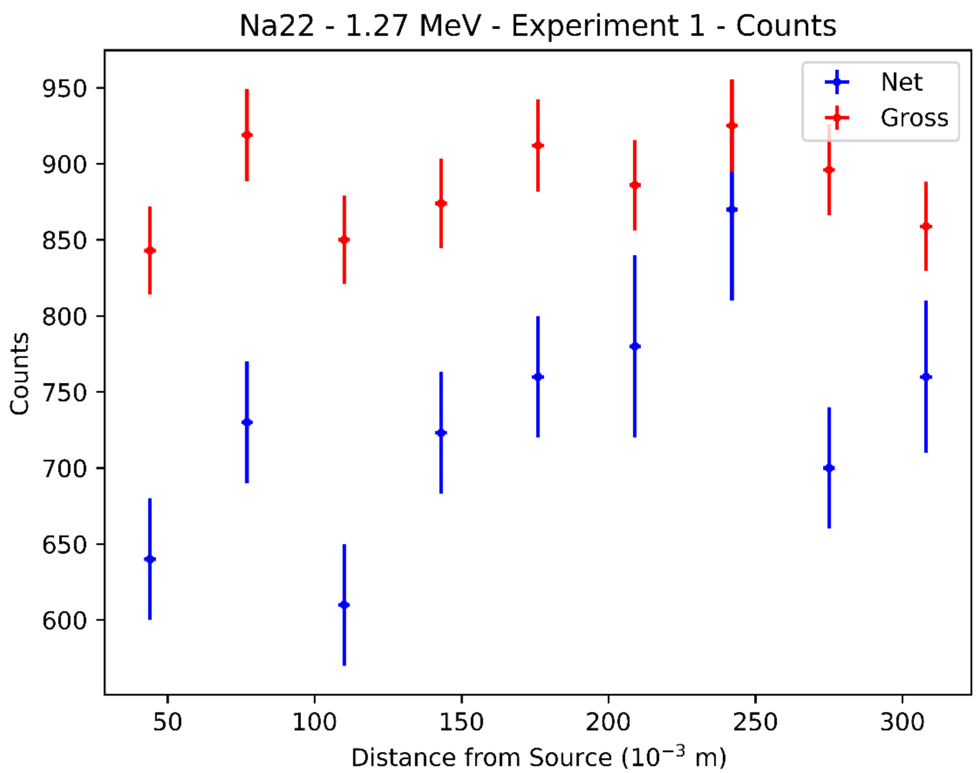

Figure 3: The results for the sodium 1.27 MeV peak graphed as count vs absorber distance. We do not see the trend we expect

The results however do not show the trend we expected. Instead, there is no defined trend with either the net or gross counts. This data is best modeled by a straight line, which indicates that for this 1.27 MeV peak the geometry does not affect the count or count rate.

Potential Changes:

Due to these results, I would not recommend changing the experiment in any way, as this is not a source of error for peaks in this energy regime.

Geometry in relation to the photoelectric effect:

However, at lower energies, where attenuation is dominated by the photoelectric effect and not Compton Scattering, there may be different results. In order to investigate this, we analyzed the 31 keV peak of Barium as it exists in the regime where the photoelectric effect dominates.

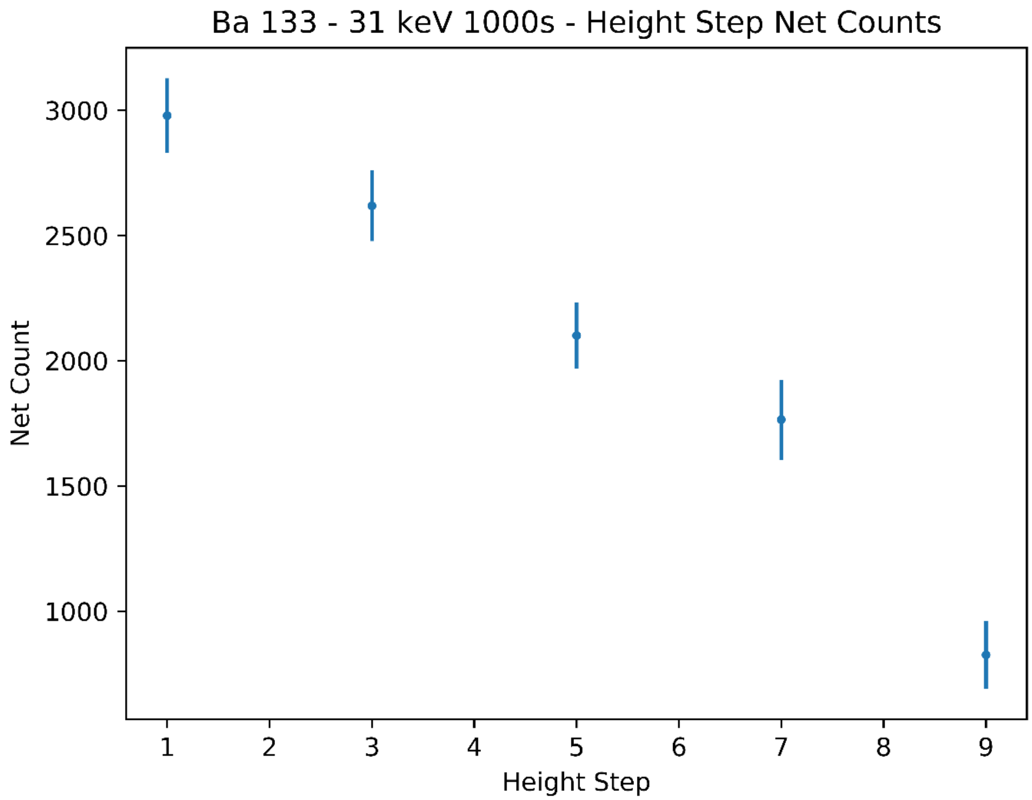

Figure 4: The results for the Barium plotted as counts vs. fractional height step. Here we have a significant downward trend.

The results show us a downward trend as the absorber is moved closer to the detector. This cannot be explained with the model we discussed earlier for the 1.27 MeV peak, as while more gammas scattering into the detector makes sense for Compton scattering, it does not make sense for the photoelectric effect as gammas that are attenuated by the photoelectric effect are absorbed by the absorber and not scattered. Therefore, we need a new explanation.

While I have no definite answer for why we witness this effect, I theorize that this is due to some kind of saturation of the absorber. This saturation could occur because the gammas that hit the detector are more tightly packed when the absorber is close to the source. The gammas overlap and pass through a smaller section of the absorber. This smaller section is easier to saturate and thus more gammas get through after it is saturated. When the absorber is moved away from the source, the gammas spread out and have to interact with a larger section of the absorber. This increase in the area of absorber that is hit by the gammas leads to a decrease in the count rate, as the absorber won't be as saturated.

Another theory is that the other gammas that would have missed the detector help saturate the absorber and allow more of the gammas to pass through to hit the detector. When you move the absorber further from the source, then less of these extra gammas are there to saturate the absorber and more of the gammas that are going to hit the detector are absorbed leading to a reduced count.

Potential Changes:

From these results, I would recommend placing the absorber close to the detector when taking spectrums of Barium, as it does not affect the higher energy 356 keV peak (because it lies in the regime where Compton Scattering dominates), but it minimizes the lower energy peaks. This change won't have a massive effect, but it should improve the data and could account for some of the error we seek to explain.

Centroid Drift:

Another potential error source we looked at was a potential shifting of the centroid of the energy peaks. We witnessed this some when we were conducting the experiment in the fall. It seemed to be a function of absorber thickness, and so we investigated this. When investigating this we also found another potential source of error: the initial startup time of the detector. Our decision to investigate this was too late into the process to request more data, and was instead based on a selection of data given to us by the lab staff. It is not ideal as mentioned later, but it still provides some insight. In order to obtain the centroids for this data, the peaks were fitted to Gaussian and from the fit parameters we determined the centroid.

Absorber Thickness:

In order to investigate this, we analyzed data taken for Na-22 where the absorber thickness was changed while the height remained constant. We did this for both the 511keV and the 1.27 MeV peaks.

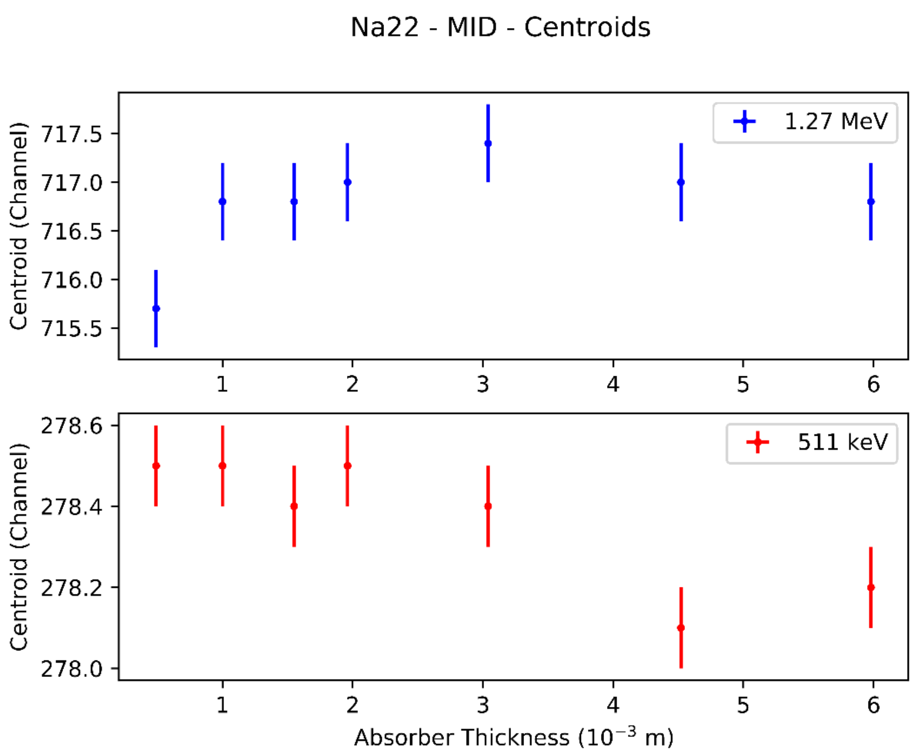

Figure 5: A plot for both energy peaks of Na-22 with the Centroid as a function of absorber thickness. Notice the small range of the y-axes.

From the results we see that there is no consistent trend relating the absorber thickness to the centroid of the gaussian. However, this data is far from conclusive, as the absorber range is small only ranging from 0.5 to 6mm. Ideally, we would gather data with a broader range of thicknesses (on the order of centimeters), as that is closer to the average depth a photon of this energy will penetrate aluminum before it is likely to interact. However, we did not have the time, and this is the only data we had access to. Give time we would like to reexamine this with a larger range of thicknesses

Potential Changes:

From the data we have, as limited as it is, I cannot recommend any changes to the experiment, as absorber thickness does not seem to affect the position of the centroid of the peak.

Time:

However, when plotting the above centroid values, there was one time where there was a notable centroid shift. Figure 5 only contains measurements when an absorber was there. If you include the calibration data taken, the graph instead looks like this.

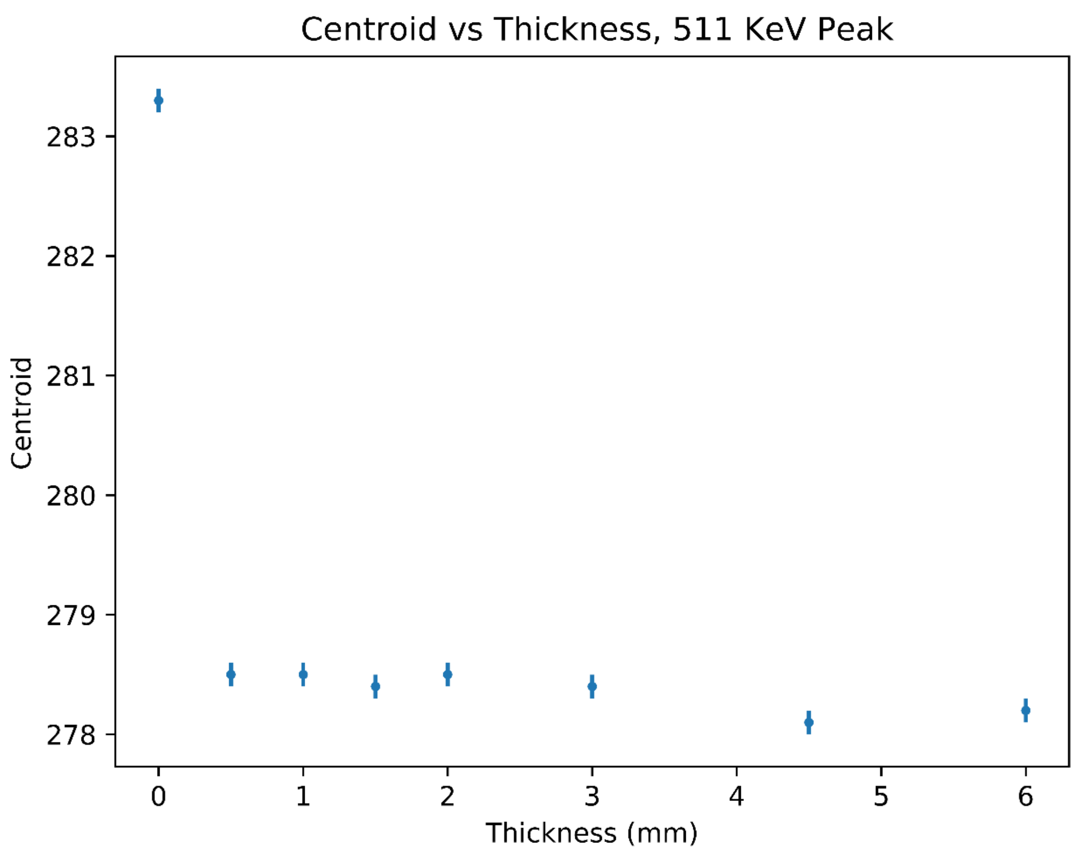

Figure 6: Centroid vs Thickness with the calibration point (thickness = 0) included

While one might think the cause of this is related to the thickness, it's actually related to the time difference between when the different samples of data were taken. Based on the data in the files, the calibration data was taken at 10:22am and the rest of the points listed were taken at 02:58 pm. Since the points taken after this time change remain consistent, while the outlier was taken approximately 4.5 hours before the others it is likely that this difference is related to the time elapsed.

In order to look at this further, we examined the set of data taken soon after the calibration data was taken.

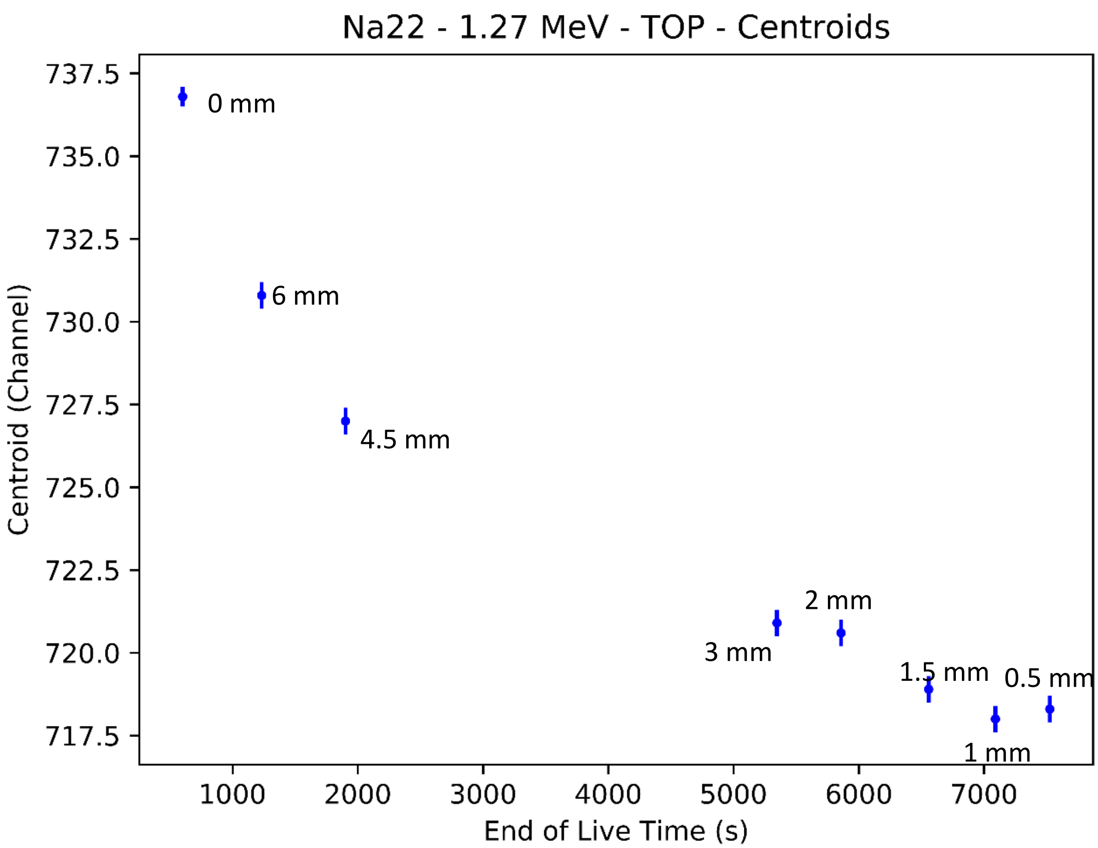

Figure 7: The centroid of the 1.27 MeV peak as a function of the live time. The thicknesses are labelled.

As you can see, as time passes the centroid begins to shift downwards. While it may appear to be a function of thickness, the fact that it starts with 0 and then goes to 6 would be illogical. Thus, we see that the detector will have some drift until it has been on for approximately two hours, where it levels out and stays consistent. This is likely due to some kind of heating inside the detector. After enough time has passed, whatever part of the detector that depends on heat has reached a consistent temperature and produces consistent results. This could lead to the error people seemed to have, as they would likely start with a thin absorber and test thicker ones as time passes, leading to the appearance that the thicker absorber caused the shift, when in actuality it was a result of the absorber warming up.

Potential Changes:

In order to avoid this problem, I would allow the detector to run for two hours before data collection begins. This will ensure that the centroid doesn't shift between measurements and cause error in the data.

Conclusion:

While we could not define all the potential unaccounted error sources, we managed to identify two factors that did not seem to affect the data, and one potential issue that could affect the data. These are important, as if we had the time, we could examine further potential issues. Given enough time we could pinpoint most of the unexplained error, but as it stands now, we have shown some results. In order to reduce potential unseen error sources, I suggest that when taking spectrums that involve gammas in the regime where the photoelectric effect dominates, we should place the absorber as close to the source as possible to reduce the counts, and the detectors should be allowed to run for at least 2 hours before collecting data to allow them to reach the point where they produce consistent results.

Appendix:

A) Example of the fitted peaks.

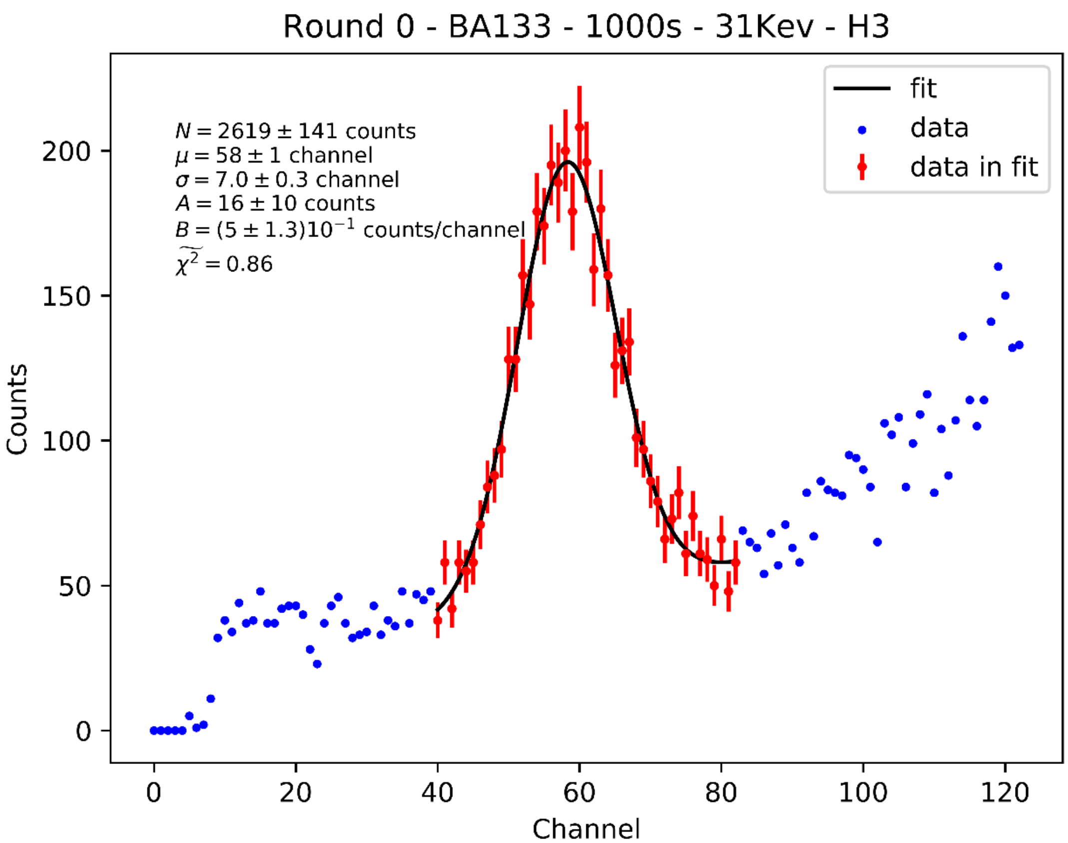

Figure 8: An example of the fits done on the gamma peaks. Fit parameters are included in an inlet on the graph.

B) Link to Data

https://github.com/tpr0p/phys21103-gx2.git