1 Data Reduction

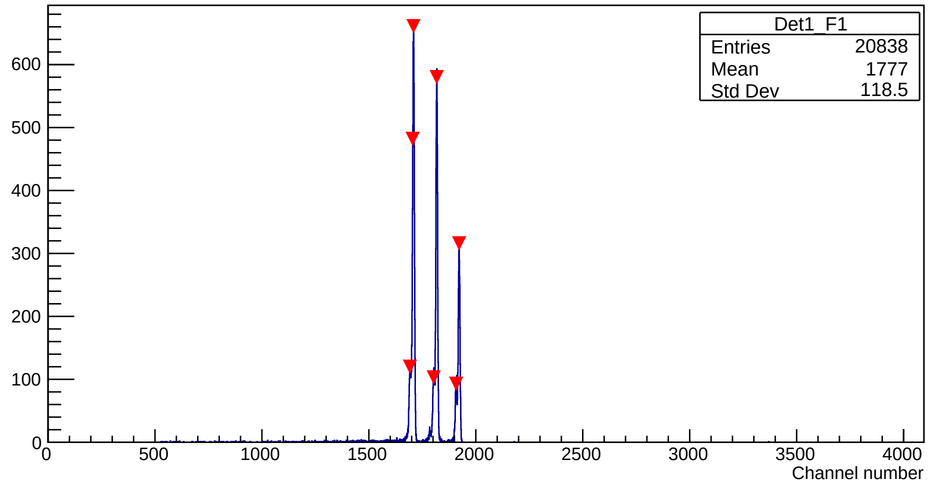
1.1 Calibration

To actually calibrate the detectors, we use an α-source with a known spectrum. The source is placed in the target position, and each detector is in turn placed in front of the source. The radioactive source used to calibrate this setup contained ^{148}Gd, ^{239}Pu and ^{244}Cm. Each isotope has a prominent main peak, and several sub peaks. The proprieties of which is listed in table 1.1.

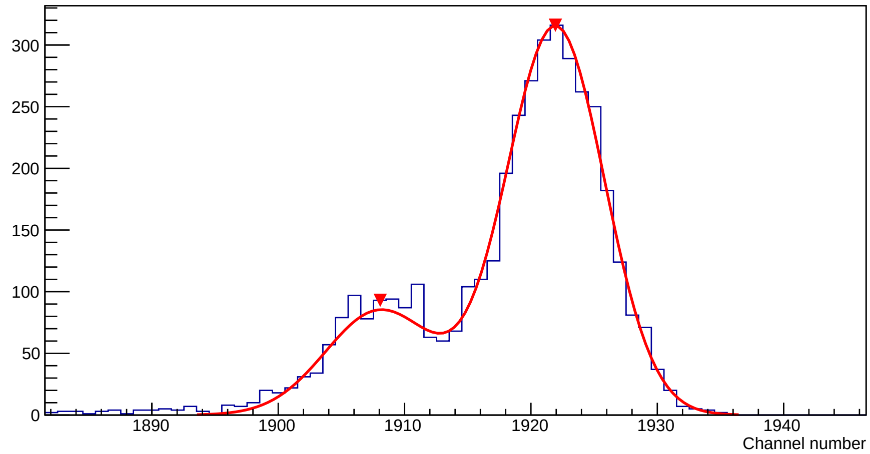
Isotope	E_α $[keV]$
^{148}Gd	3182.690
^{239}Pu	5105.5
	5144.3
	5156.59
^{244}Cm	5762.64
	5804.96

Table 1.1: Decay energies for each isotope used in the calibration.

A typical single strip spectrum is shown on fig. 1.1a, where the calibrator has given an estimate of where the peaks are, illustrated by the red triangles. fig. 1.1b shows a closer look at the ^{244}Cm peak, where the red line shows the `Calibrator`-fit over both the main peak and the sub peak.



(a) A spectrum of the calibration source, with channel number along the x-axis. The red triangles indicate the positions the `Calibrator` has guessed as the peaks.



(b) A closer look at the ^{244}Cm peak on the above figure. The red line is a fit performed by the `Calibrator`, and the red triangles indicate the guessed peaks.

Figure 1.1: Calibrations of detector 1

1.2 Identifying the particles

After utilizing the AUSAlib tools, the data is ready to be analyzed. Even though the theory dictates that a decay will consist of two α-particles and one β-particles, it is not realistic to just assume that each detected event will consist only of this configuration of particles.

Therefore we need some cut on what events we will allow through to the analysis. Specifically we are going to impose 3 cuts on the data, a angular cut, a momentum cut and a multiplicity cut.

1.2.1 Identifying a hit

After a hit has been has been detected, and all the relevant information has been extracted from the hit, we can start to analyze what type of particle has hit the detector.
A important distinction between an α-particle and a β-particle is the different interactions with a detector. An α-particle will be completely stopped by a standard $60\,\mu$m detector, while a β-particle will pass through it, depositing only a small amount of energy.
This is the reason for the SSD's behind each DSSD. The idea is that only a β-particle will be detected in the SSD's, so if a hit has some energy in a DSSD *and* the corresponding SSD, it will be classified as a β-particle.

This approach however does not work as well as intended. Often what happens is that the thin DSSD will not pick up any energy deposited, and the hit will therefore not be counted. But not all of the detectors are $60\,\mu$m. We have two detectors that are around $1000\,\mu$m thick. These detectors are much better at picking up a signal from a β-particle, so one of the criteria for being a β-particle in this setup is to have hit either Det2 or DetD.

These two criteria are however not enough to uniquely determine that a hit was a β-particle. We still have to consider the events where a detector has multiple hits. Since a SSD gives no usable information regarding where a particle has hit, we cannot say which particle was a β-particle and which where a α-particle.
Therefore if the β-particle criteria are true, we mark the particle as a *possible* β. But since it might as well have been a α-particle, we also mark it as such. Every hit that does not uphold to the β-particle criteria are of course marked only as a possible α-particle.

When all the particles have been identified, we impose the first cut to the data. A multiplicity cut that says we need at least two α-particles. If there are less, we discard the event.
When we at least have two distinct particles that can be α-particles, we look at their mutual difference in momentum. The particle pair with the least difference in momentum will be chosen as the only α-particles that can be present in an event. Then we have assured that every other particle we see in the event, is possible β-particle candidates.
When each particle has been identified or discarded, all remaining particle-specific information is stored to the given particle for easy analysis henceforth.

1.3 Angular cut

When ^{8}Be decays, and produces the two α-particles, it will do so under conservation of momentum. The decay in any direction, but the angle θ between them will be close to 180°. Therefore the first cut that we give to the data, is that two of the particles that are αcandidates, must have a mutual angle of close to 180°.

On fig. 1.2 a plot of all the the mutual angles are shown. A quick glance will give that most particles will have mutual angle of close to 180°.
By looking at this, we see that most of the angles will lie close to 180°, and now we must decide exactly where to do the cutoff. By taking a sharp cutoff at $\cos(\theta) \geq -0.99$, we will exclude a great deal of good measurements, on the other hand, a too soft cut will not accomplish anything, as too many "wrong" particles will let through the check. By trying different cuts, we have found that $\cos(\theta) \geq -0.95$ is a good cutoff, and this corresponds to 161°.

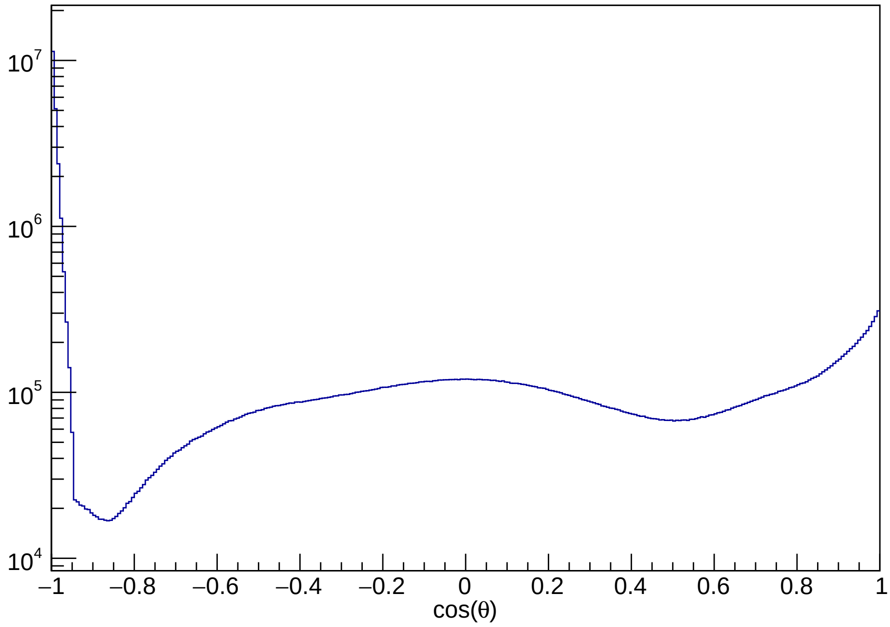


Figure 1.2: A histogram of all the mutual angles between all particles.

1.4 Momentum cut

The second cut we perform on the data is a *total* momentum cut. On fig. 1.3 the total momentum for the two identified α-particles are shown. A prominent peak lies around 13.000 keV/c, and ends around 40.000 keV/c. We impose a cut of maximum 40 MeV/c, as this will include the large amount of pairs lying in the peak, which must be α-αpairs. A α-particle with energy 1500 keV will have a momentum of 105 MeV/c, and a free electron of 3000 keV will have a momentum of 1.7 MeV/c. The majority of particles lies around these energies, and no matter where the β-particle will hit, the total momentum is still much larger than the 40 MeV/c cutoff.

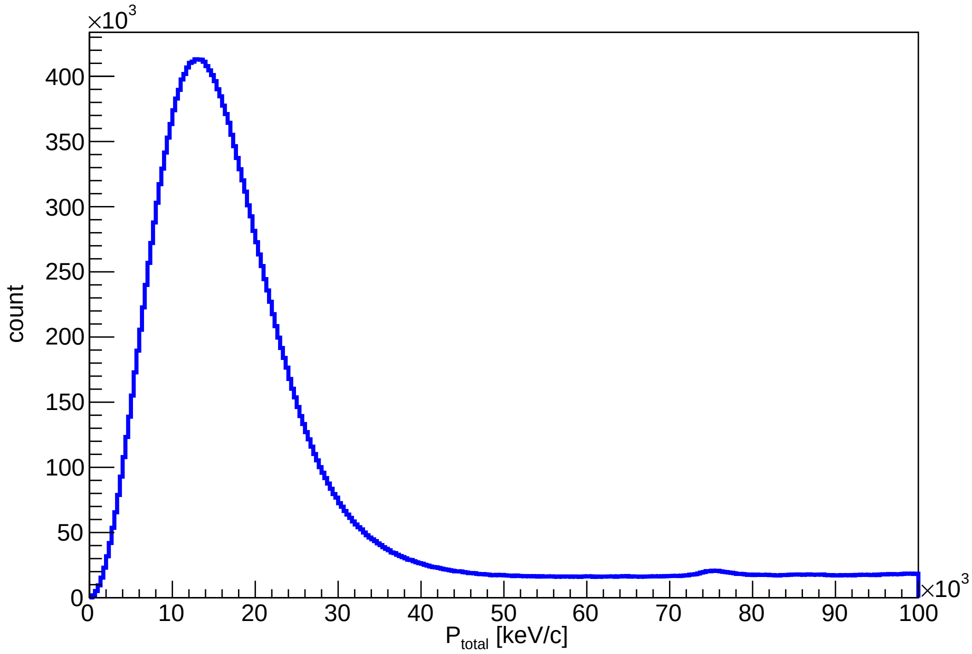


Figure 1.3: The total momentum of the two α-particles.

1.5 Multiplicity cut

The last cut that we want to impose on the data, is a multiplicity cut. This cut is just to ensure that we have the amount of particles that we expect. Therefore a hard criteria is that there must be at least two distinctly identified α-particles.

With regards to the β-particles, we are more loose. Here we say that there must at least be one, but more can occur. This is quite rare, but the we still take that event into account, as the β-particles should have an isotropic distribution, and therefore should not in any case be affected by the other α-particles. On fig. 1.4 we see the multiplicity of β-particles, and in most of the events, we have not detected any β-particles, and when we do, there is a even fewer events with more than one beta. So most of the time, we are in the expected case with two α-particle and one β-particle.

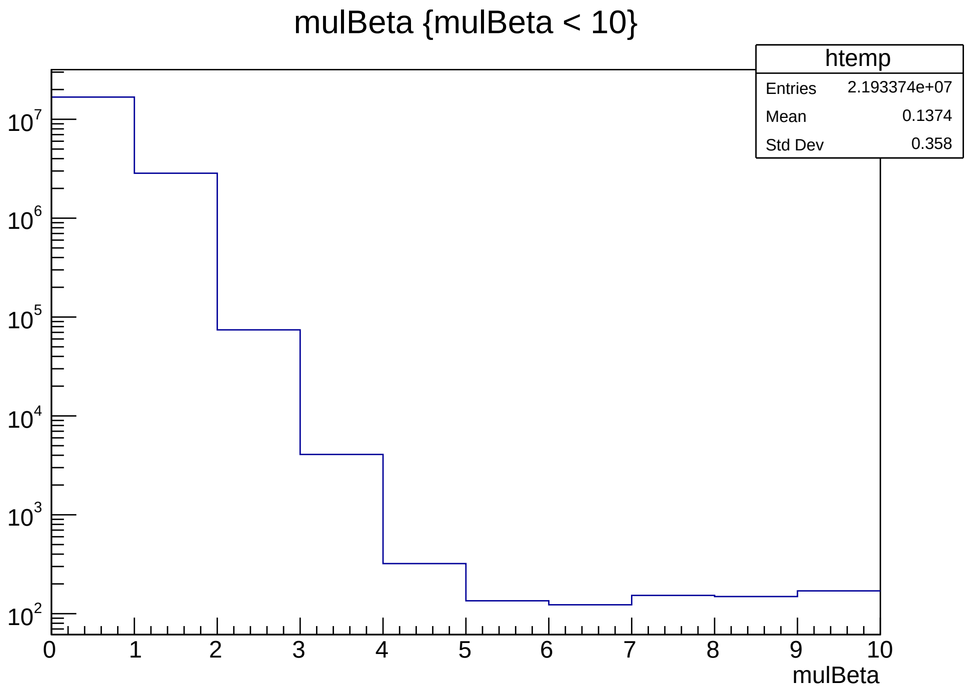
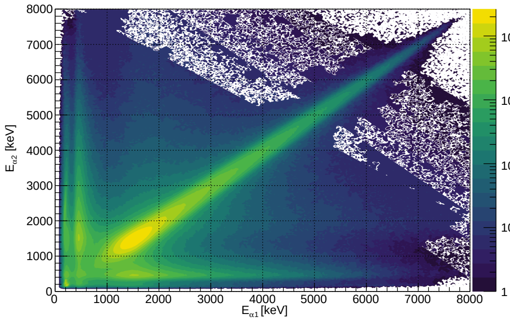


Figure 1.4: The multiplicity of the β-particles.

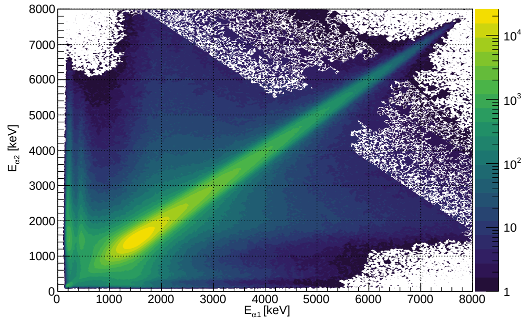
2 Analysis

2.1 The effects of the cuts

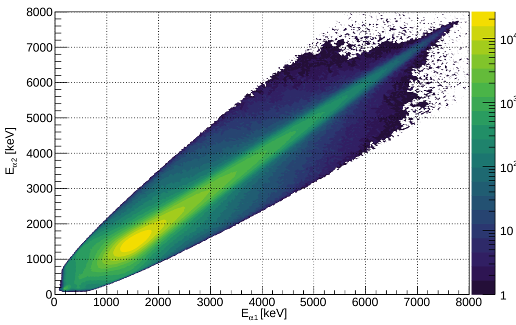
How does the cuts imposed in the previous chapter affect the data then? First we need to look at how the data looks, without any cuts. On fig. 2.1a the energy of the first α-particle ($E_{\alpha 1}$) is plotted against the energy of the second α-particle ($E_{\alpha 2}$). This gives us a nice view of what is considered α-particle pairs. There is a prominent line going diagonally through the graph, where both particles have around the same energy. This line is expected, as the α-particles will have close to equal energy, when decaying from ^{8}Be.
This means that there is a lot of particle pairs that have been identified as α-α, but properbly was α-noise, noise-noise, α-β or β-β pairs.
The lines occurring from $E_{\alpha 2} \approx 400\,\mathrm{keV}$ are a clear example of a α-β pair. In this line, $\alpha 1$ has been identified correctly as a α-particle, which will have energies ranging from 500-6000 keV, whereas the the other particle has a more constant energy, corresponding to the energy a β-particle can deposit in a detector. So by doing no cuts at all, we are left with a lot of cases where we have no real control over what particle type we are dealing with.



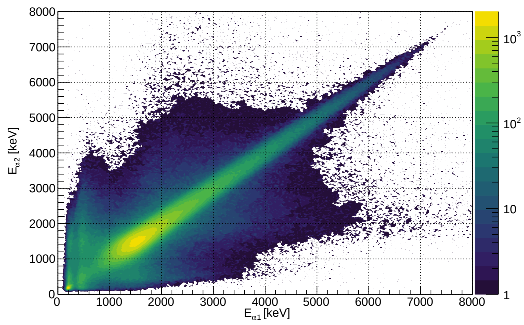
(a) No cuts on the data



(b) An angular cut. The angle between the two partcles must be greater than 160°.

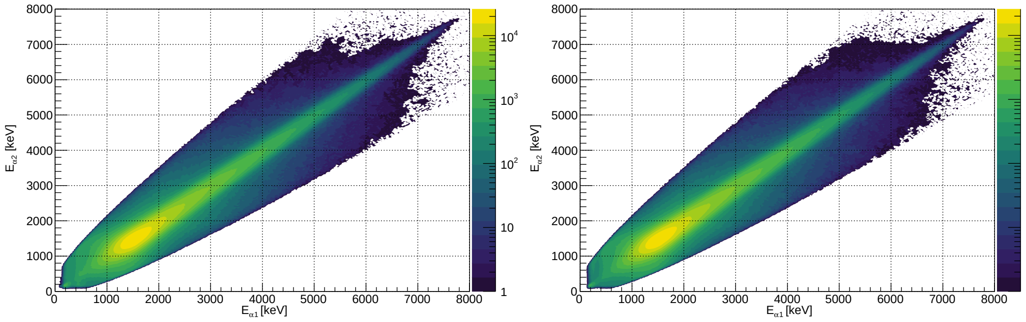


(c) A momentum cut. The total momentum of the particles must be less than 40 MeV/c



(d) A β-multiplicity cut. There must exist at least one β-particle and two α-particles in the event.

Figure 2.1: A collection of the different effects the cuts impose on the energy of the α-particles. On all the above figures, the energy of the first α-particle ($E_{\alpha 1}$) is plotted against the energy of the second α-particle ($E_{\alpha 2}$). The intensity scale is in logarithmic, to get a better view of all the different particle configurations.



(a) Only moment **(b)** Ang and moment

Figure 2.2: A comparison of the momentum cut with and without the angular cut.

2.1.1 The effect of the angular cut

By imposing the angular cut, we get the first real reduction in data. If the angle between the two α-particles are less than $\cos(\theta) = -0.95 \approx 160°$, we sort away a good part of the β-α pairs, as seen on fig. 2.1b. But there are still a good portion of wrong pairs left, and we move on to impose a cut on the momentum of the particles.

2.1.2 The effect of the momentum cut

Again the aim is to sort the data, so that we can identify the particles. On fig. 2.1c the total momentum of the two particles has been limited to a maximum of 40 MeV/c. This cut sorts away all of the vertical and horizontal lines from a β-αpair. With this drastic cut, it looks like there is no use for the angular cut, which might be true. On figure 2.2 we can see the comparison of the effect of the momentum cut, with and without an angular cut. There does not seem to be a very large difference. Since momentum already takes the direction of the particles into account, as well as their energies, the angular cut will seem a bit redundant. However, we keep the angular cut on the data, as it will not take away any "good" measurements, but only some noise that slips through the multiplicity cut.

2.1.3 The effect of the multiplicity cut

The multiplicity of the β-particles should not interfere so much with the α-particles, but looking at fig. 2.1d, we see a drastic change in the pairs with energies far from each other. This is due to a general reduction in data. With the requirement that there must be one β-particle present in the event *and* that it must have hit either Det2 or DetD, we are left with a lot fewer measurements, which in turn gives a lower probability of noisy pairs.

2.1.4 The combined effect of all the cuts

By combining all of the cuts we are satisfied with the sorting of particles. On fig. 2.3 we see the effect of all the cuts. There is a very prominent line of particles with roughly the same energy. The line is thinner at higher energies, and widens as it goes towards lower energies. The reason for the widening, is the recoil energy from the β-decay. If the α-particles have low energy, they are more susceptible to other forces around it, and the therefore are greater chance of having the exact same energy.

So far we have only considered that the α-particles are sorted correctly. But there is still a question for weather the β-particles will be clouded by wrong identifications. On fig. 2.4 we see the energy deposited in the two detectors that are capable of measuring β-particles, and the pad behind Det2. The energy from the pad and DetD, shows one peak around 400 keV and 300 keV, respectively. Det2 shows two peaks, one close to 400 keV, and one close to 800 keV. This is rather interesting, as we do not expect β-particles to deposit two different energies. Both detectors and the pad where 1000 μm thick, so we expect that the energy deposited would be roughly the same.

2.2 The exitation energy of ^{8}Be

With the α-particles sorted correctly, we can start to look at the excitation energy of ^{8}Be. All products of this decay will hit our detectors, and the entire

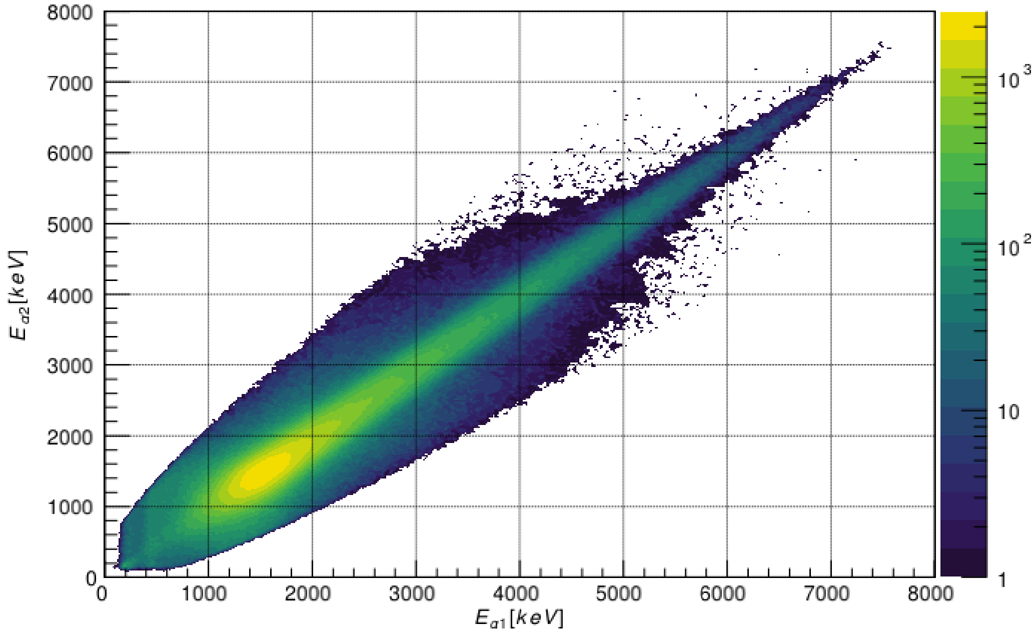


Figure 2.3: The energy of the first α-particle plotted against the energy of the second α-particle. All of the data reduction cuts are used here.

energy of the decay can be measured. On fig. 2.5 the sum of both α-particles energies are shown.
on fig. 2.5 is a spectra of the excitation energy of ^{8}Be. This looks like bataraajaajaajaaja

2.3 Angular efficiency of the setup

Since the detectors are unable to cover the entire solid angle, there will always be some mutual angles that are more likely to be measured. If we only look at one detector, a very large number of angles are not covered, but small mutual angles such as $\theta \approx 0$, are very easy to measure, as it is just a measurement of two particles in the same pixel. This effect becomes apparent on fig. 2.6, where the angular efficiency is shown for Det2. For a single detector, there cannot be angles of $\theta = 90$ and higher, as the detector is flat. In this detector, the lowest angle found was $\cos(\theta) = 0.21 = 77°$.

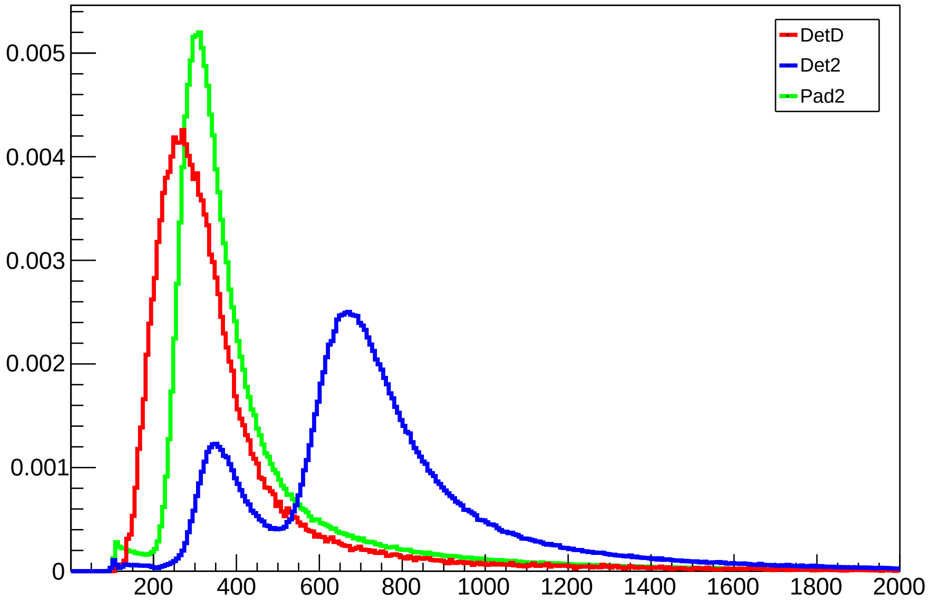


Figure 2.4: Energy deposited by β-particles in Det2 (blue), DetD (red) and Pad2 (green). PadD has been omitted, due to an error in the pad.

In this setup however, we a cube of square detectors, who's normal vectors are all pointing in towards target at the center. This gives a much larger coverage of all mutual angles. The placement of the detectors gives that angles around $\theta \approx 90°$ are also very favored. This makes sense, almost no matter what pixel was hit, there is a corresponding pixel 90° to both sides. In the same way, will there always be a corresponding pixel $\approx 180°$ from each pixels. This effect can be seen on fig. 2.7.
This histogram was created by using the spacial coordinates of the entire setup. First the positions of each pixel in each detector was found. Then two loops running over each pixel pair i, j, finds the angle between these pixels and saves it.

There is still a geometric effect that is not accounted for in the above analysis. We still need to consider that not all pixels in the detector has the same

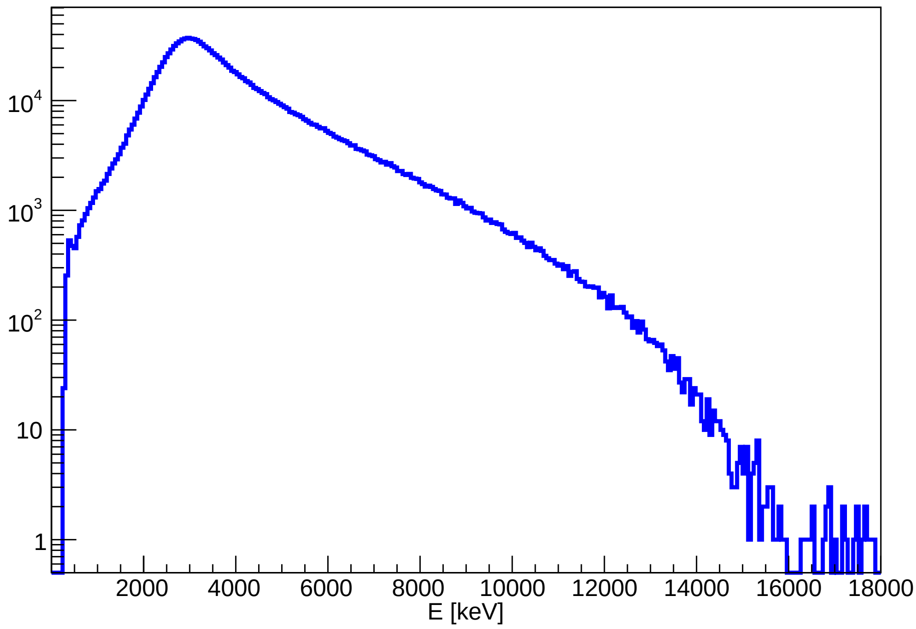


Figure 2.5: The energy spectra of both α-particles, that is the exitation energy of ^{8}Be.

effective area. A pixel furthest out in a detector will have a effective area smaller than the area of a pixel in the center. This effect can be seen on fig. 2.8a. Here we see that there is a much higher count of particles hitting the center of the detector, and fewer hitting the edges. A white line crossing through the middle is a defect strip, which did not measure anything. Sadly, some of the detectors had defect strips, but on a large scale it was not very noticeable.

To account for this effect, each pixel will be associated with a corresponding area-efficiency (Eff_A). This is calculated as

$$\text{Eff}_A = \frac{A\cos(\theta)}{4\pi r^2}, \tag{2.1}$$

where r is the distance to the pixel, A is the area of the pixel and θ is the angle between the inverted normal vector of the pixel and the line from the center to the pixel. A illustration of the scenario can be seen on fig. 2.9.

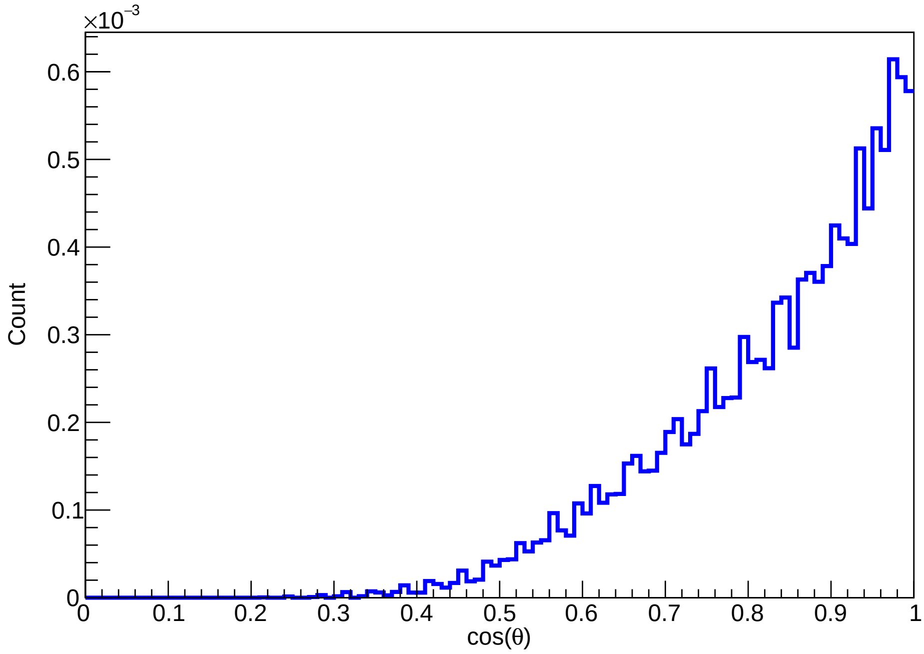


Figure 2.6: The angular efficiency of a single detector (Det2). For one flat detector, there can never be angles of 90° and higher.

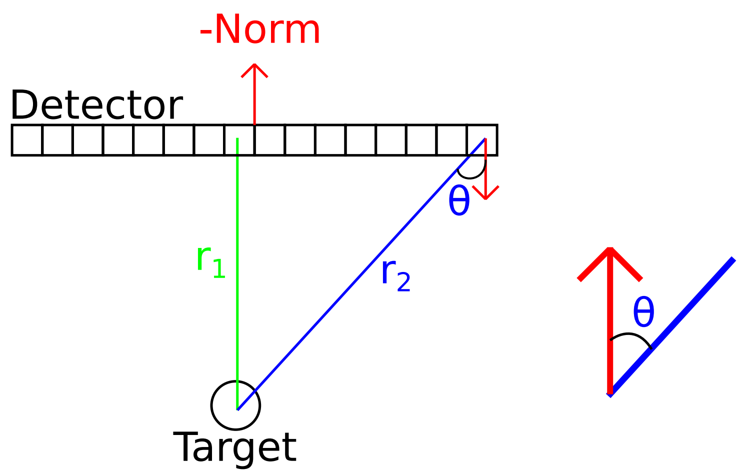


Figure 2.9: Geometry

On fig. 2.10 two histograms can be seen. The red line represents the angular efficiency of the setup, without accounting for the relative area of the pixels, while the blue line is a weighted histogram for the same angles, with each

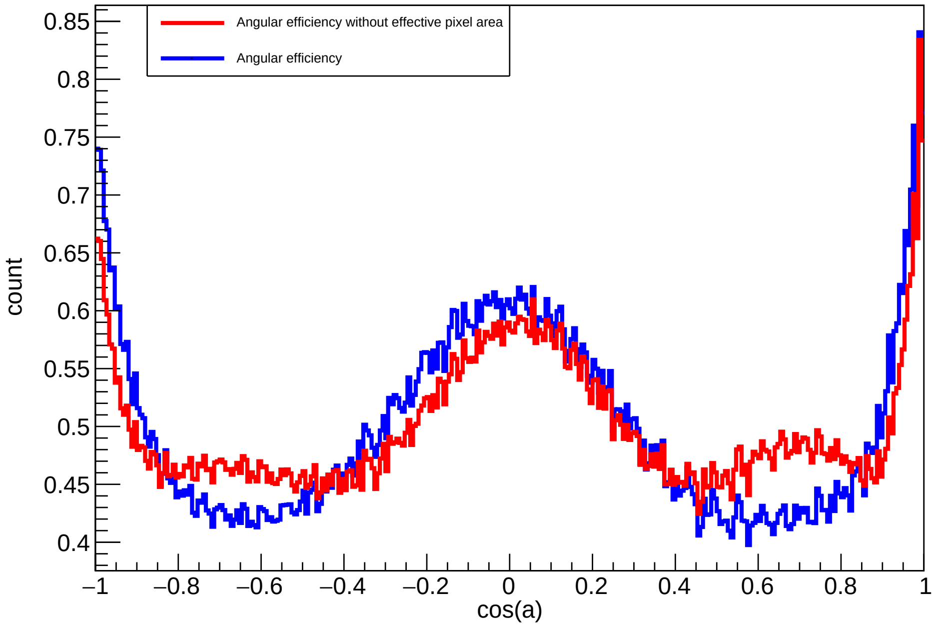
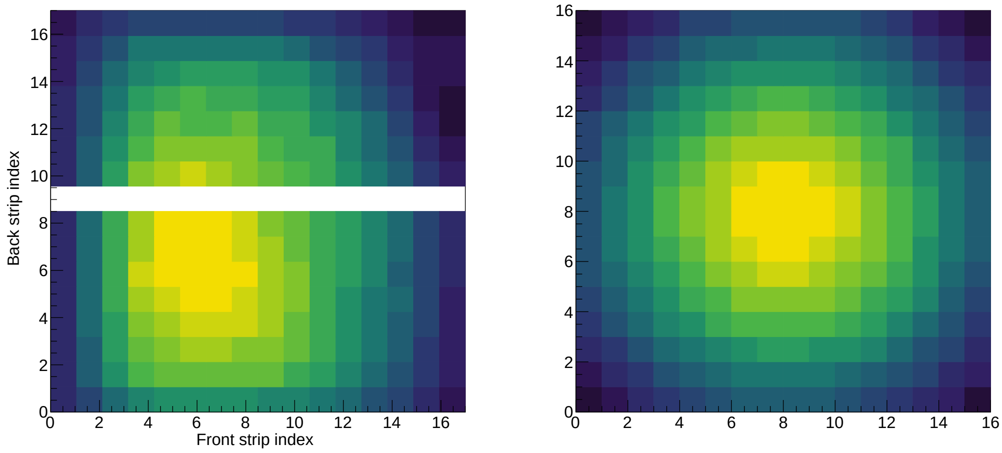


Figure 2.7: Two normalized histograms of the angular efficiency of the entire setup. The red histogram does not account for the effective area of a pixel. The blue is the true angular efficiency.

pixels relative area accounted for.
The form of the two histograms are quite similar around 1, 0 and -1 but in between there is a rather prominent difference. Therefore it is important that the effective area of the pixel is accounted for, when we in section 2.4 will look at the angular correlations of the β-particle in the setup.

2.4 Angular correlations of α-particles and β-particles

From what we know in ref til beta = isotrop the β-particles must have an isotropic distribution. Since we only have two detectors in the setup that are capable of measuring β-particles, we cannot measure the angle from one particle to something constant, i.e. the beam. Therefore we measure the



(a) A plot over the number of hits in each strip for Det2. The white line in the middle is a defect strip, that did not measure anything.

(b) A theoretical intensity Det2.

angle between both α-particles and the β-particles. This is done by first finding the angle between the first α-particle α_1, and create a histogram of this. Then the angle between the second α-particle α_2 is measured, and a histogram is created. The two histograms are then added, to get the full picture of the mutual angles of the particles. This can be seen on fig. 2.10 as the green line.
The blue line is this figure is the angular efficiency for the specific case, where the α-particles can hit in any given detector, but the β-particles can only hit in the two specific detectors Det2 and DetD??. The two histograms has both been normalized, for a better comparison. By dividing the two histograms with each other, we get a better comparison. If they where to be close to equal, we would see a flat curve. But what we see on fig. 2.11 is not very flat. There are small fluctuations in the line, which stems from the inaccuracy of calculated angular efficiency. But the main shape of the curve is at most time not around $y = 1$.
There are two different explanations as to why this might be. The first explanation is that the beam did not hit the target in the center. The calculated efficiency assumes that the beam hits precisely in the middle, but

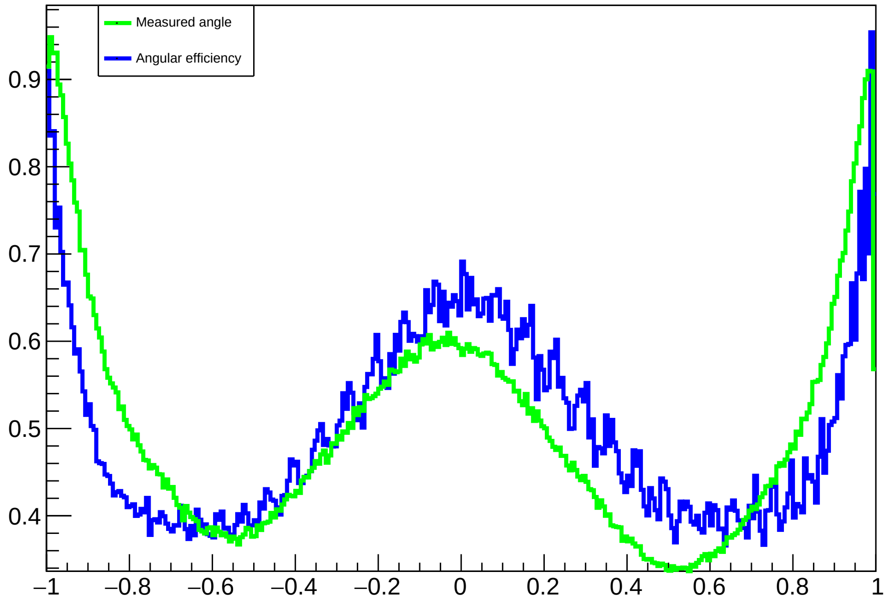


Figure 2.10: Some figure of the efficiency of the setup without efficiency of each pixel.

in any setup, there can be a few millimeters of errors.
By finding the angular efficiency of the setup, with different values for the center and comparing this to the measured angles, we have found a slight correction for the center of the beam. This can be seen on fig. 2.12a, where the beam has been moved to the coordinates $(-3, -3, 0)$, as opposed to the previous of $(0, 0, 0)$. The division fo the two histograms on fig. 2.12b shows a more stable line from $\cos(-0.4)$ to $\cos(0.4)$, but the edges are still not very alike. Looking at $\cos(1)$, we see a rapid fall, which indicates that we have measured a lot fewer parallel β-particles and α-particles than the setup is designed to handle. This can be due to the fact that some of the strips where defect. The calculated angular efficiency does not know which strips where defect, and and will therefore have a lot higher efficiency for parallel particles. The defect strips will therefore also play a role in the grand scheme, and is a possible explanation as to why there is a difference in the calculated and the measured data.

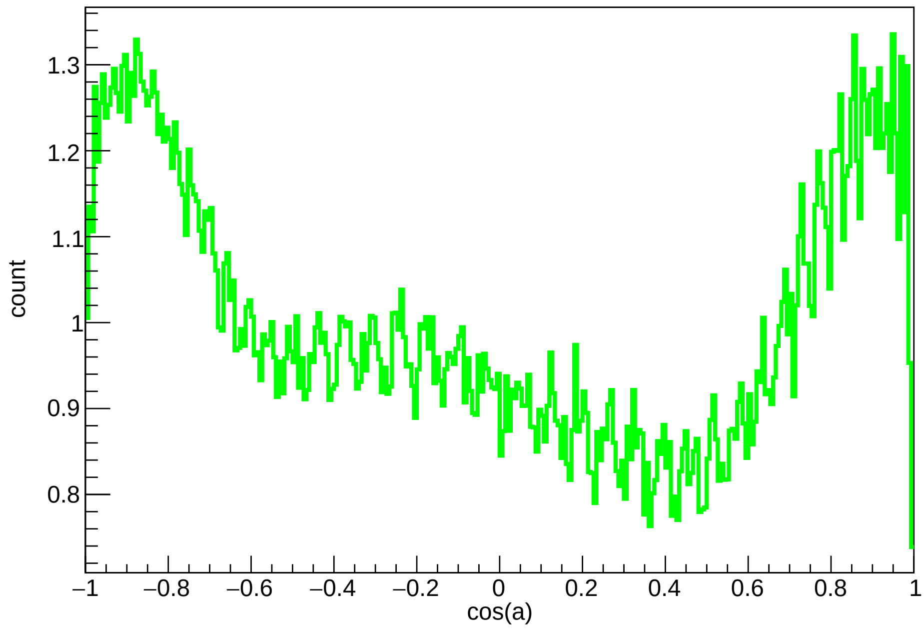
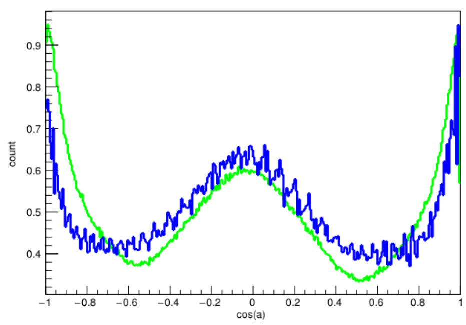
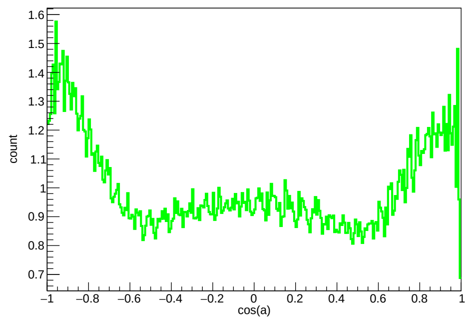


Figure 2.11: Data divided by the angular efficiency.



(a) The angular efficiency and the data, with a correction for the center of the beam.



(b) Measured β- α-particle angular distribution divided by the calculated angular efficiency of the setup, with a correction for position of the beam.