SPECIALE TITEL HER!

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1 Introduction

In this thesis i will make a thorough analysis of the the delayed β-decay of ^{8}Li. The first part of the thesis will will be governing getting data from a detector sorted into an appropriate data structure that can be analyzed. The second part is a more physics analysis of the α-particle pair that is produced, and their correlation to the β-particle. Lastly a discussion of the result and setup will be conducted.

2 Theory

3 Experimental Methods

The data used in this thesis stems from an experiment carried out at the IGISOL facility, at the University of Jyväskylä. Originally the experiment was scheduled for May 2020, but was postponed due to the ongoing Corona pandemic.

3.1 Detector setup

The detection setup consists of 6 double sided silicon detectors (DSSD), and 6 single sided silicon detectors (SSD). The detectors are $5\,\mathrm{cm} \times 5\,\mathrm{cm}$ and placed in a cube around the a target in the center, as shown on figure **??**. The setup is designed with measuring the opening angle of the β in mind, and therefore the detectors covers 51% of the solid angle.

3.2 Experimental setup

The setup is designed to measure $\beta\alpha$ angular correlations in the β-delayed particle decay of ^{8}Li. When measuring multiple particles, the setup is highly dependent on the coverage of the solid angle. Therefore the setup is designed to have a large solid angle coverage, with high α-particle resolution, while still being able to measure β-particles.

This is has been achieved by creating a cube of six double sided silicon detectors (DSSD), all backed by a 1 mm single sided detector (SSD). To gain the largest solid angle, the detectors where placed as close to one another as possible. A 3D printed case was designed to hold the detectors in place, and achieved a solid angle coverage of 51% for the DSSD's. An illustration of the setup, together with the different detectors' thickness can be seen on fig. 3.1. Even though the setup was designed to hold 12 detectors in total, there where only 11 detectors in the actual experiment. This was due to one of the SSD's being defect, so it was removed from the setup.

3.3 The detectors

As mentioned above, there where two types of detectors present in the setup. The first type is the Double sided silicon detector. As the name suggests, it consists of two sides, a front layer and a back layer. Each layer consists of 16 strips, that are placed in rows next to each other. The two layers are then arranged so each side are mutually orthogonal, which defectively makes pixels where each strip intersects a strip on the other side.
The strips on the front side are p-doped, while the back side are n-doped. When a charged particle hits the detector, it will ionize the atoms in the semi-conductor, and produce a electron-hole pair. The number of electron-hole pairs is proportional to the energy of the charged particle. The bias voltage on the detector collects the electrons and holes on opposite sites of the strip, where the charge is collected on aluminum contacts and a signal is measured. Energy is not deposited in these contacts, and therefore they constitute to a so called dead layer.
The detectors are square 5×5 cm and with their 16×16 strips, they have an effective gird of 256 pixels of 9 mm. 4 of the 6 detectors have a thickness of $60\,\mu$m and a dead layer of 100 nm dead layer. These detectectors are the ones called Det1, Det3, Det4 and DetU in the setup seen on fig. 3.1. The other 2 detectors (Det2 and DetD) where both 1 mm.

The other type of detector was the SSD's also known as pads. They are different from the DSSD's, in that they only have one side, and no strips. Therefore they do not contain a grid, the same way the DSSD's do, and will therefore not provide any information as to where on the detector a particle has hit. But the reason they are in this setup, is because they are thicker. They are used to measure the energy deposited by a β-particle, and to determine if a given particle is a β-particle. An α-particle will deposit all of

its energy into the first DSSD it encoutner, and be effectively stopped compleatly by it. But a β-particle will deposit allmost no energy in a thin DSSD, and travel through it, ending up depositing some energy in the SSD.
Therefore one can roughly distinguish the α-particles from the β-particles, by observing wether a particle has a hit in the DSSD and the SSD.

Since there are also two thick DSSD's in the setup, one can also get some information from a β-particle from these thicker detectors, as it will deposit more energy in these detectors.

3.4 AUSAlib and ROOT

ROOT is an object oriented C++ framework that is designed primarily for data analysis in high-energy and nuclear physics. It was created at CERN in 1995, and has since grown and become the dominant analysis software at both CERN and many other nuclear and particle physics laboratories. ROOT was designed to handle large amounts of data with high computing efficiency.
ROOT makes an intelligent data structure by creating a "Tree" with the class `TTree`. This tree will then have "branches" which corresponds to some variable of the given detection event, such as the energy of the front strip or identity of the detector. This TTree then allows for reading of an individual branch, while ROOT takes care of the memory management. One can also store a TTree to the disk in the form a .root file.

ASUALib is a tool that build on top of ROOT. It was created by the subatomic group at Aarhus University. Before this tool was created, everyone in the group had to more or less create their own tools to get data from the detectors into a useful data structure. This meant that a lot of time was wasted just trying to access data from experiments. AUSAlib was therefore created, so the basic tasks of data extraction was automated.
AUSAlib has a lot of functionalities, but there are XX tools that was used in this thesis, namely the *Sorter*, *Calibrator* and the *AbstractSortedAnalyzer*.

3.4.1 Unpacker

The `Unpacker` converts raw data from the detectors into a ROOT TTree. This is done by using the unpacking program `ucesb` ref. This will setup the branch structure of the data. Some of these branches are `FT` and `BT`, which is a vector of the `TDC` (time) values for each event, for the front and backside of the detector. They are vectors because they contain information for each particle hits in a given time slot, for which there can be multiple. There are also the branches `FE` and `BE`, which is the `ADC` (energy) associated with the events.

3.4.2 Calibrator

Since the detectors work, by measuring an electrical charge that comes from the charged particle, the detectors needs to translate a specific charge to energy deposited.
To do that, we use the `Calibrator`-tool, which is designed to convert a channel number into an actual energy. Assuming that the channel numbers are linearly related to the energies, a known radioactive source can be measured, and the expected spectrum can be compared to the measured. This is done for each strip in each detector.

The `Calibrator` starts by running a peak-finding algorithm over some calibration data, to roughly identify the locations of the peaks, followed by a multi-Gaussian fit to find the most precise peak location. The positions of the peaks can then be compared to the expected energies, giving an associated energy to a given channel.

As mentioned earlier, all of the detectors have a small aluminum dead layer. All particles that pass through this layer will loses some amount of energy depending on the stopping power of the material and the effective thickness of the dead layer Δx_{eff}, which furthermore depends on the angle of incidence, θ. The relationship between the effective thickness and the actual thickness is described as $\Delta x_{eff} = \Delta x / \cos(\theta)$. This gives the measured energy as

$$E' = E - \frac{dE}{dx} \frac{\Delta x}{\cos(\theta)},$$

where E is the original energy of the particle, dE/dx is the stopping power of the material and Δx is the thickness of the dead layer.

These calculations are all handled by the `Calibrator`. As input it takes an unpacked measurement of a source, a file specifying the locations of the expected peaks and a file specifying the spacial locations of the detectors. From this it calculates the energy loss, and creates a linear relationship between channel numbers and energies. This is then written to the disk as a seperate calibration file, which can be parsed to other modules.
It is important to note that the Calibrator does not modify any data. Therefore the energy loss is unaccounted for. Instead it corrects the expected energy spectrum, which means that the resulting calibration is still valid. The energy loss correction is therefore still needed in the analysis, as the effect is unaccounted for in measurements.

3.4.3 Sorter

The sorter is used after a successful calibration. It generates a ROOT file based on the unpacked data, and applies the calibration. It is also responsible for matching and combining events from the front-side to the back-side of the detector. If there where one hit in the front side and one in the back, the mathcing is fairly trivial. If there however where multiple hits in both front and back, the `Sorter` will run a matching algorithm, which pairs the hits with the lowest energy differences.

When the events have been matched, the hits on the individual sides of each detector are merged into a single event. Therefore each event can now be considered a multiple of particle hits. This makes it possible to to associate physical properties with each particle, such as direction and energy.

There has still not been done any filtering of the data, which is what we will discuss in chapter 4.

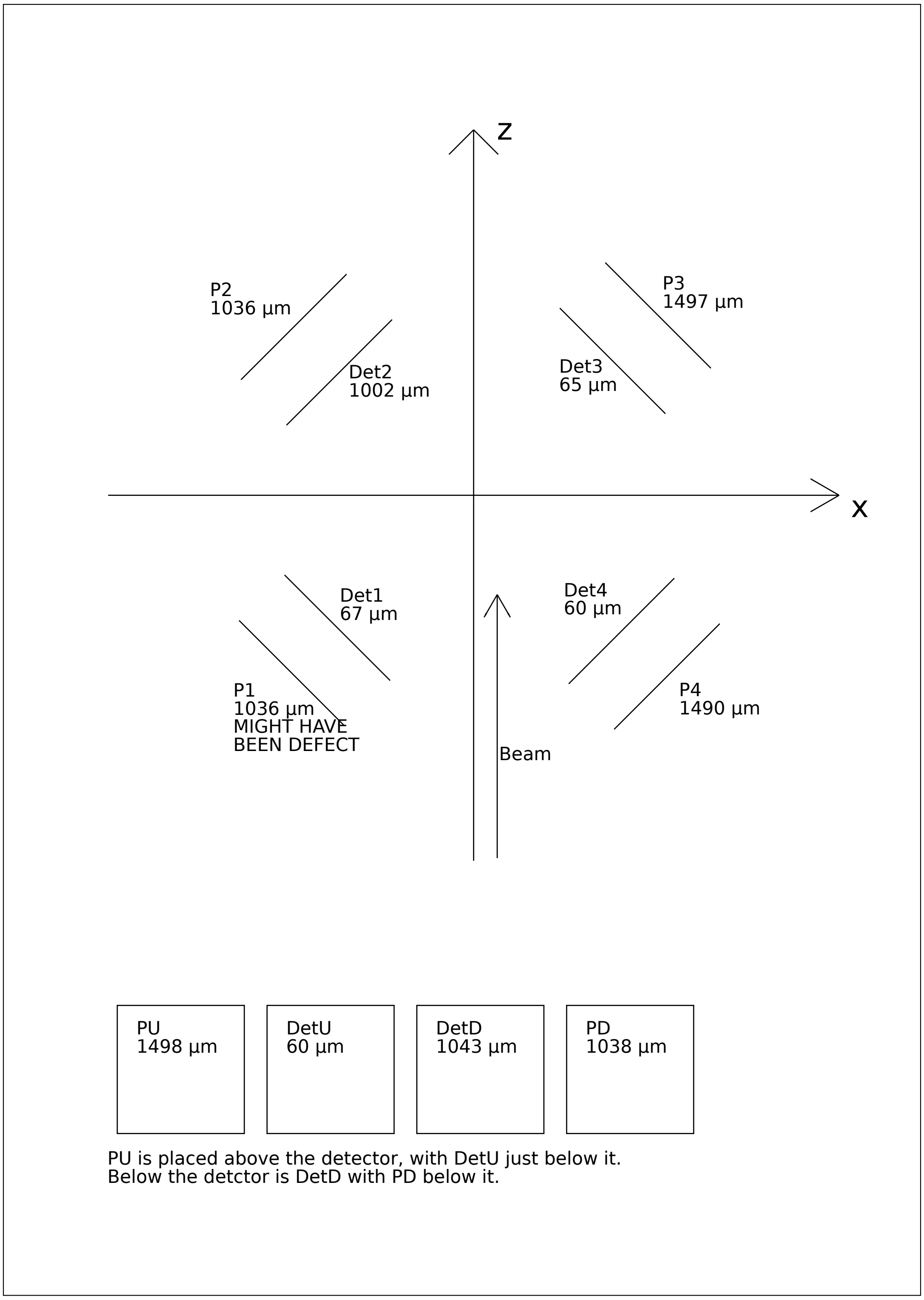


Figure 3.1: illustration of the setup. Note that the SSD P1 was absent from the actual experiment, due to failure in the detector

4 Data Reduction

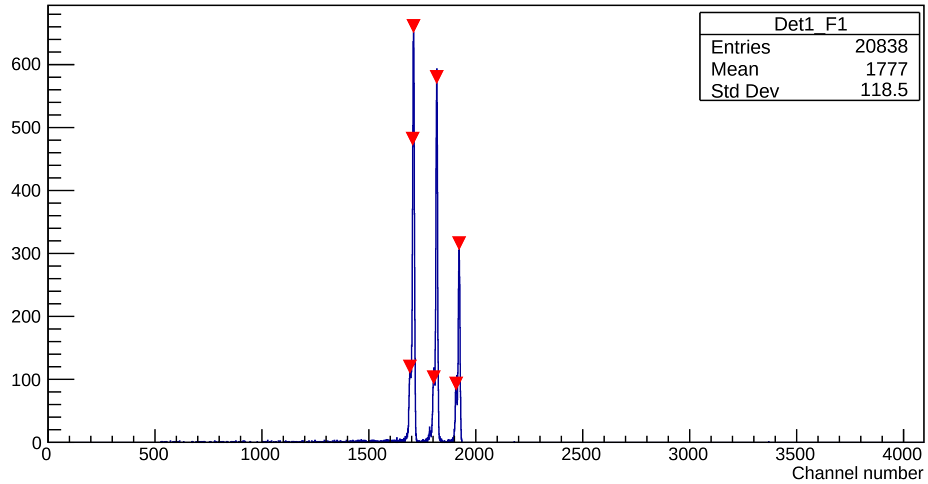
4.1 Calibration

To actually calibrate the detectors, we use an α-source with a known spectrum. The source are placed in the target position, and each detector is in turn placed infront 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 4.1.

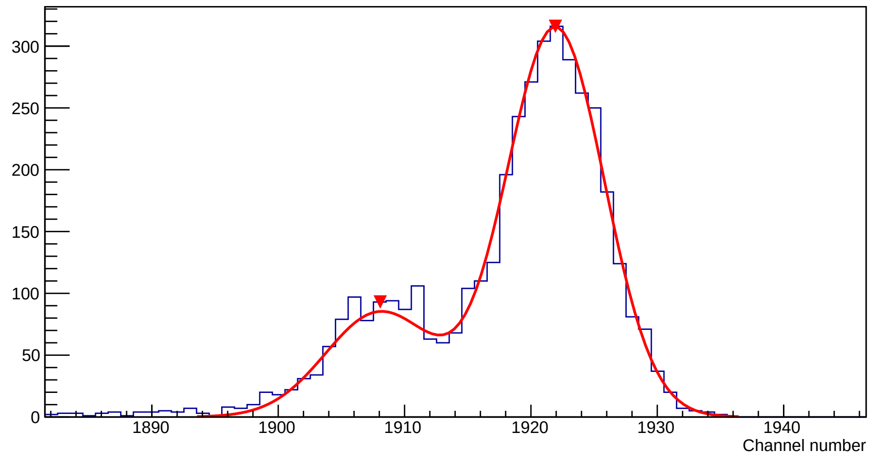
Isotope	E_α $[keV]$
^{148}Gd	3182.690
^{239}Pu	5105.5
	5144.3
	5156.59
^{244}Cm	5762.64
	5804.96

Table 4.1: Decay energies for each isotope used in the calibration.

A typical single strip spectrum is shown on fig. 4.1a, where the calibrator has given an estimate of where the peaks are, illustrated by the red triangles. fig. 4.1b 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 4.1: Calibrations of detector 1

5 Analysis

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.

5.1 Identifying the particles

When a particle hits a given detector, we have no real knowledge of what particle it is. Therefore we need to do an analysis where we identify what particle we have.
This is done in XX steps

5.1.1 Finding a hit

The first step ind identifying a hit, is to actually get a hit, and gather the different properties of the specific hit.

5.1.2 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 μm 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 μm. We have two detectors that are around 1000 μm 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 contains 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 a particle is marked as a α-particle, we also perform an energy correction, MAYBE ENERGY CORRECTION HERE??

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.

5.2 Angular cut

When a particle hits a given detector, we have no real knowledge of what particle it is. Therefore we need to use other properties of the decay to determine the particle type. 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 between θ them will be close to 180°, or $\cos(\theta) \geq -1$. 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. 5.1 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°.

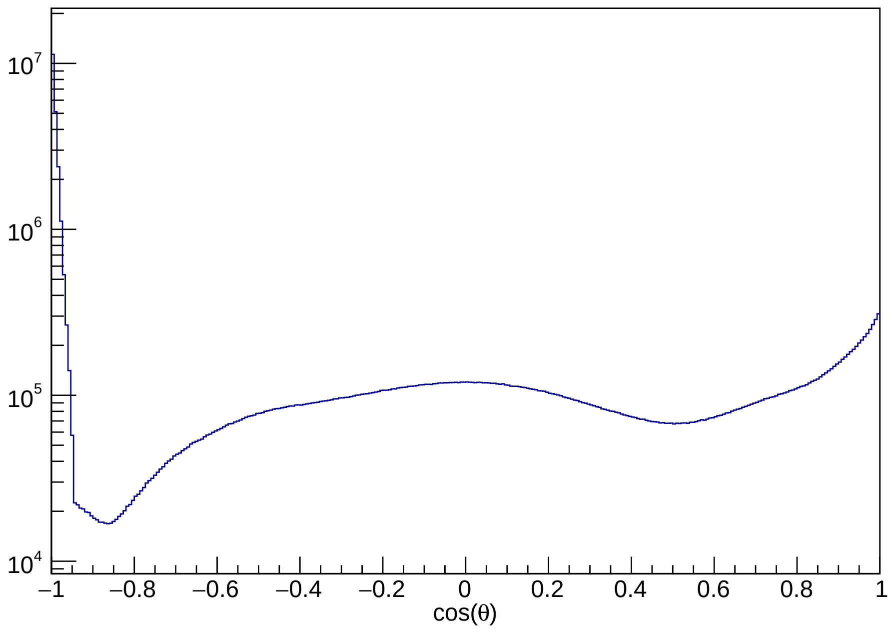


Figure 5.1: A histogram of all the mutual angles between all particles.

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.

5.3 Momentum cut

The second cut we perform on the data is a *total* momentum cut. We see on **??** the total momentum for the two identified α-particles. A prominent peak lies around SOME VALUE, and ends around 40.000 keV. SPØRG HANS OM HVORFOR 40k er godt, UNIT ER keV/c. Since there is still a large tail of higher momentum, we cut those out, and only get the particles we are sure can actually be α-particles.

5.4 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. 5.2 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.

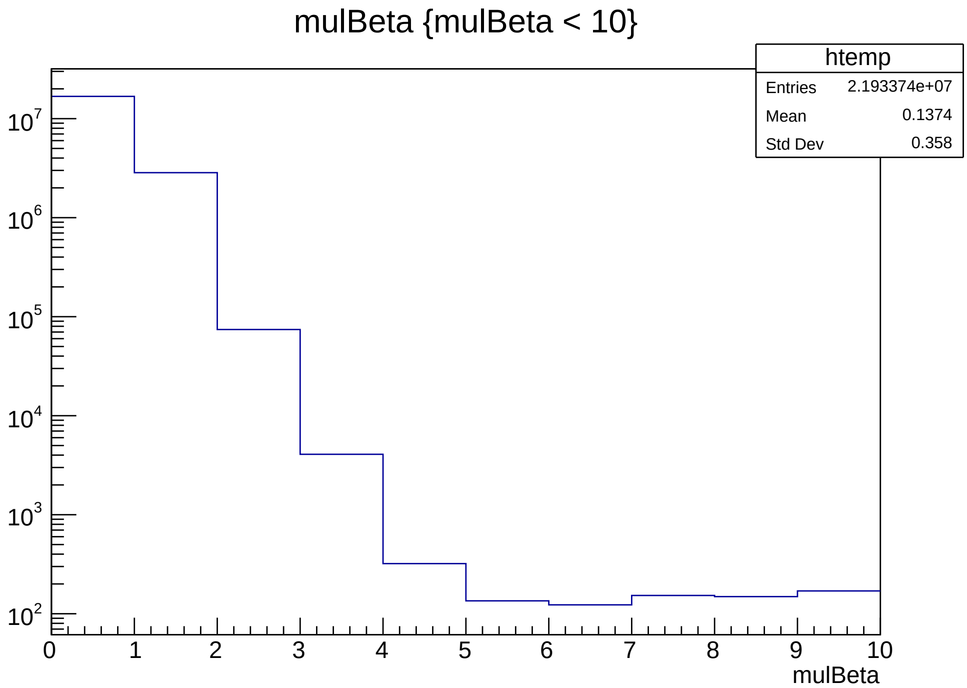


Figure 5.2: The multiplicity of the β-particles.

5.5 The properties of the α-particles

5.6 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 $\theta \approx 180°$, are very easy to measure, as it is just a measurement of two particles in the same pixel. This effect becomes apparent on **??**, where the angular efficiency is shown for Det??.

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. 5.3.
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.

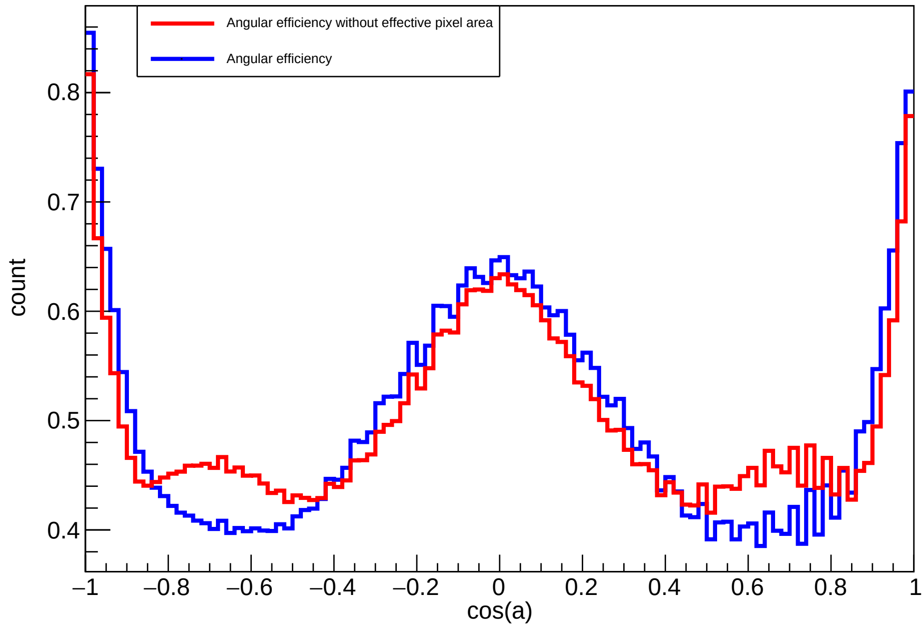


Figure 5.3: Two normalized histograms of the angular efficiency of the entire setup. The red histogram does not account for the effective area of a pixel. The blue is the true angular efficiency.

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 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. 5.4. Here we see that To account for this effect, each pixel will be

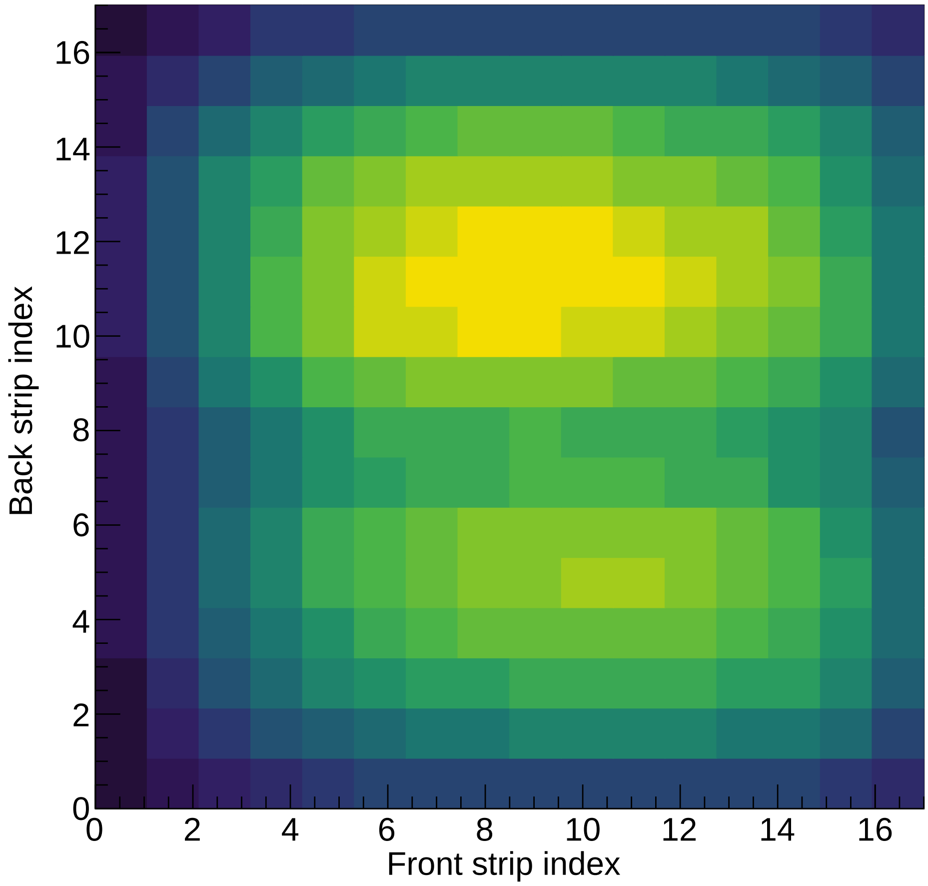


Figure 5.4: A plot over the number of hits in each strip for Det1.

associated with a corresponding area-efficiency (Eff_A). This is calculated as

$$\mathrm{Eff}_A = \frac{\cos(\theta)}{r^2}, \tag{5.1}$$

where r is the distance to 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 **??**.

On fig. 5.6 two histograms can be seen. The red line represents the angular efficiency of the setup, without accounting for the relative area of the pixels,

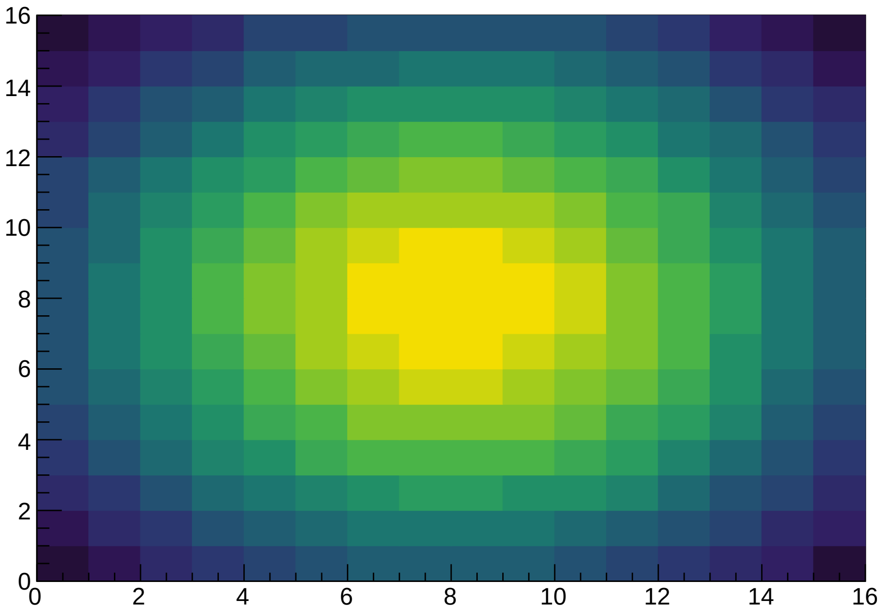


Figure 5.5: A theoretical intensity Det2.

while the blue line is a weighted histogram for the same angles, with each 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 5.7 will look at the angular correlations of the β-particle in the setup.

5.7 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 from the α-particles.

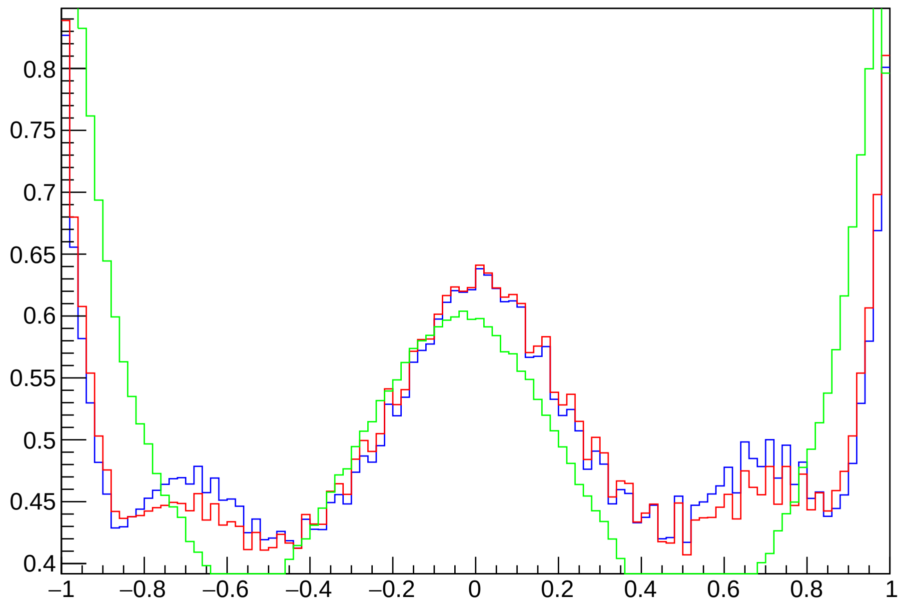


Figure 5.6: Some figure of the efficiency of the setup without efficiency of each pixel.

6 Conclusion