Calibration, resolution and efficiency of gamma ray detectors

LaBr3 scintllation detector, which we mainly used during this internship

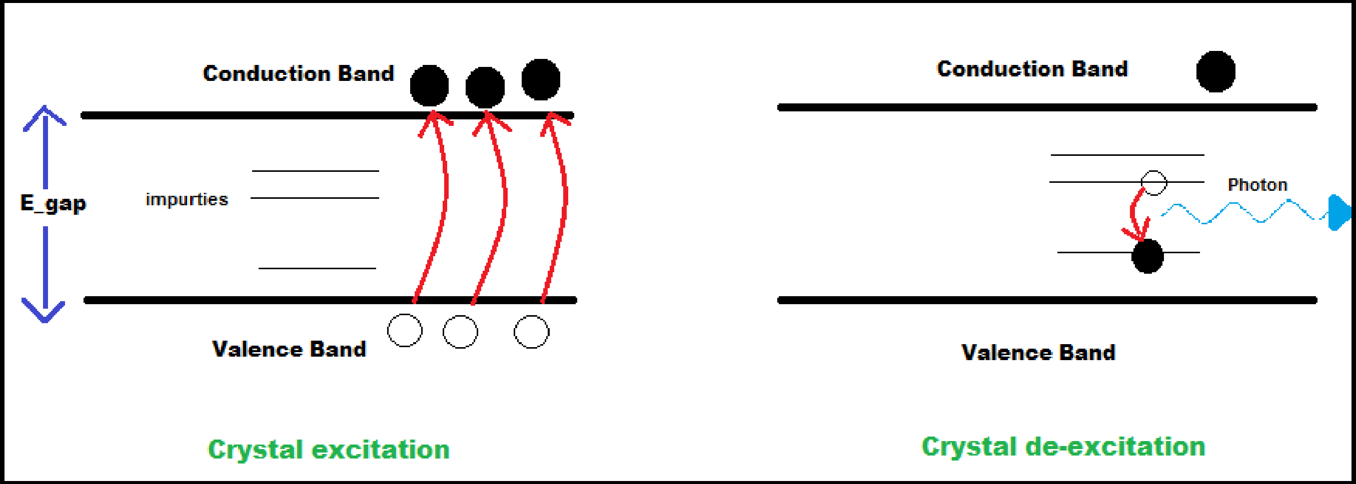
Summary

- I) Principle and characteristics of the detectors

- II) Means of data acquisition and their functionning

- III) Our experiments with the detector and the results obtained

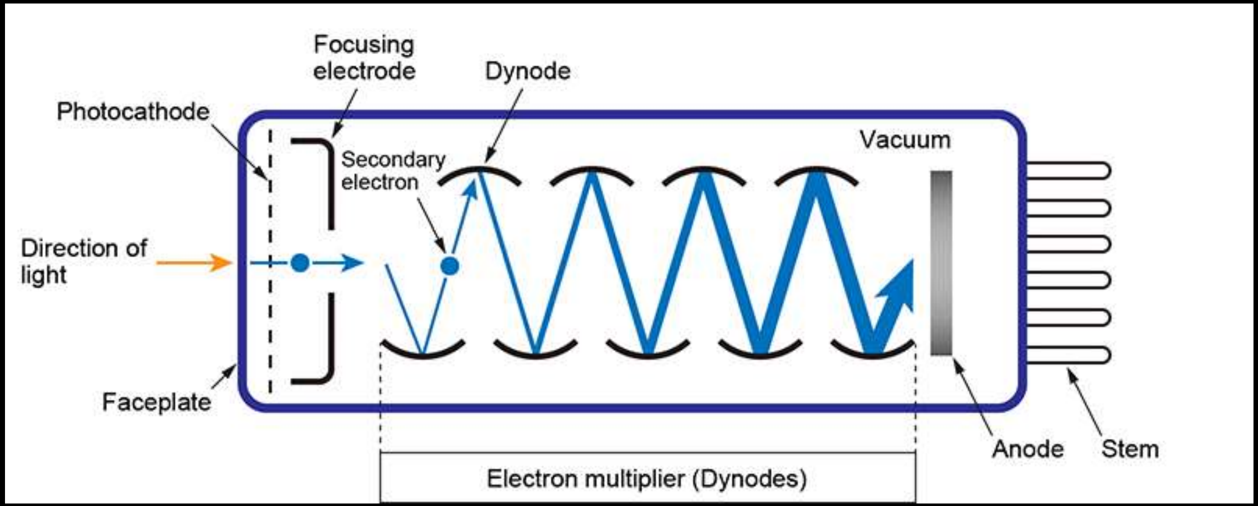
Principle and characteristics of the detectors



Scintillation principle : the crystal will absorb an incident photon and, with the help of the impurities, will re-emit it with lower energy

NaI(Tl) scintillation crystal

Principle and characteristics of the detectors

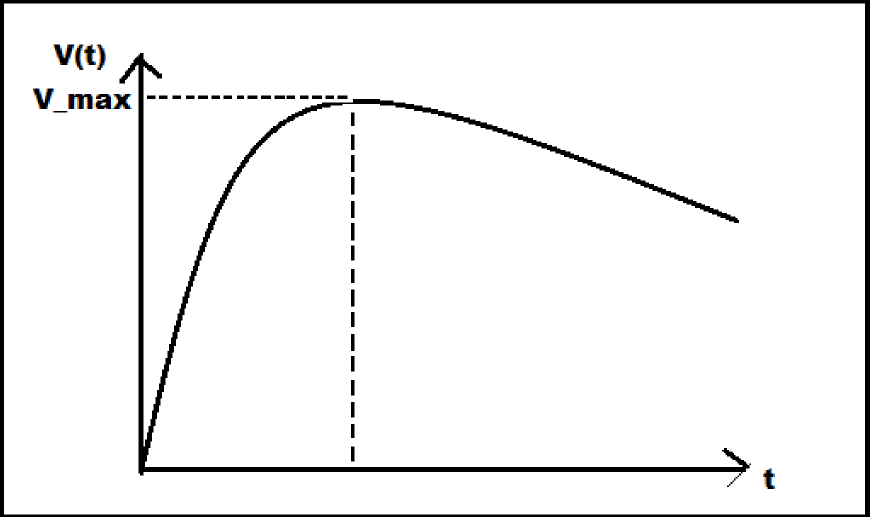


The maximum voltage is proportional to the energy deposited by the photon in the crystal.

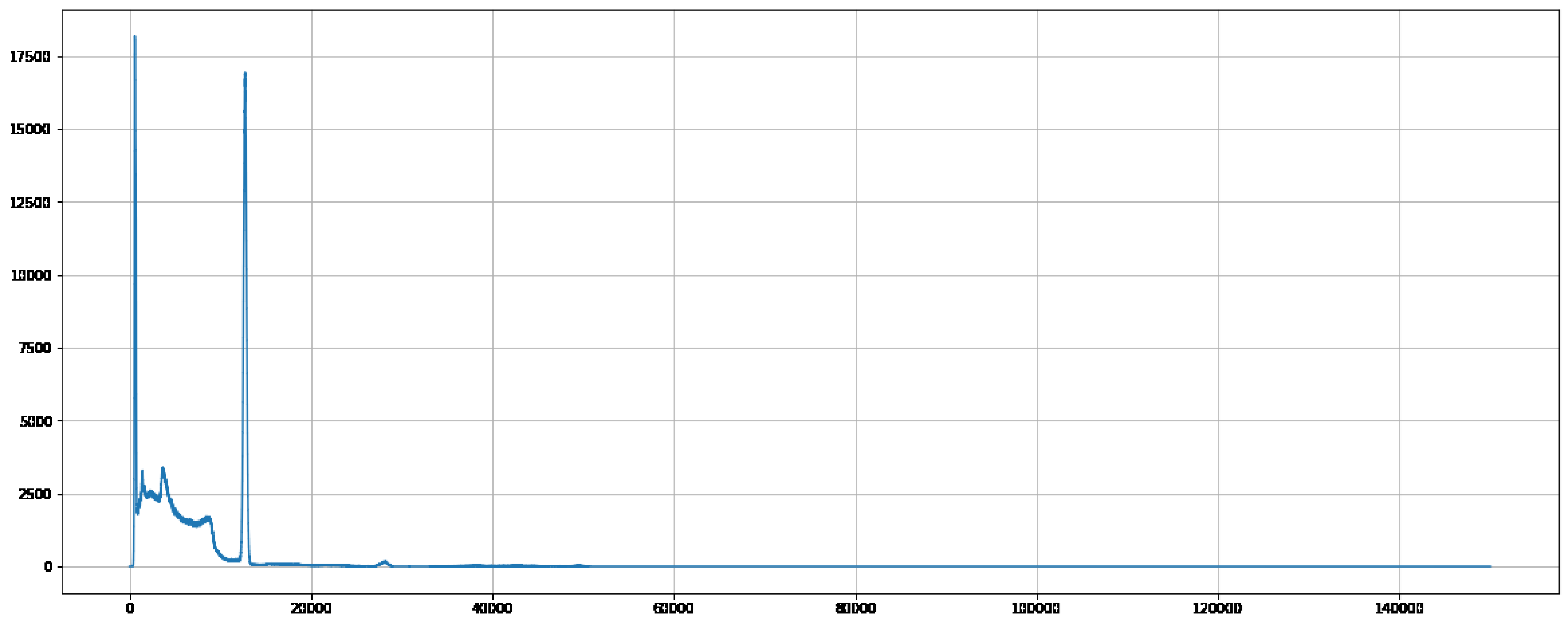
Rise time ~ 1µs
Fall time ~ 110µs
Amplitude ~ 25mV

The purpose of the photomultiplier is to multiply the photoelectrons and to collect them using the anode.

The electrons collected by the anode will then be converted into an electrical signal



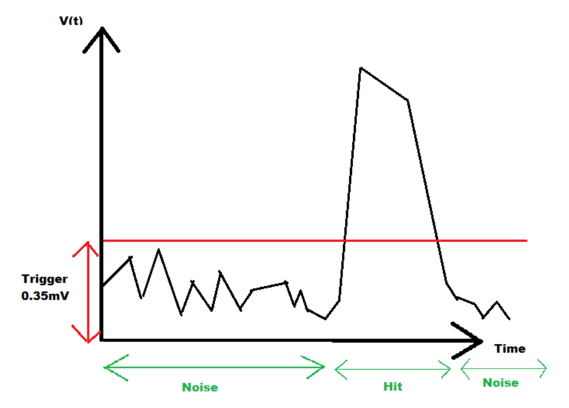
Principle and characteristics of the detectors



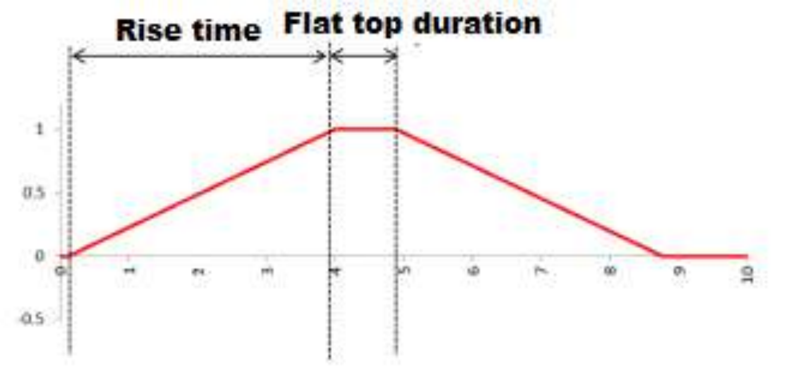
Example of a histogram of Caesium decay using the Faster software

Means of data acquisition and their functionning

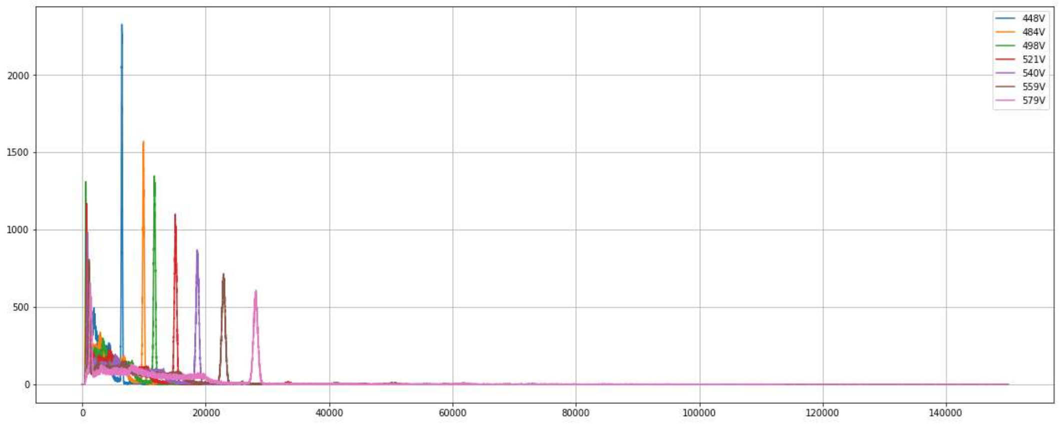
The three parameters to be taken into account :



The trigger



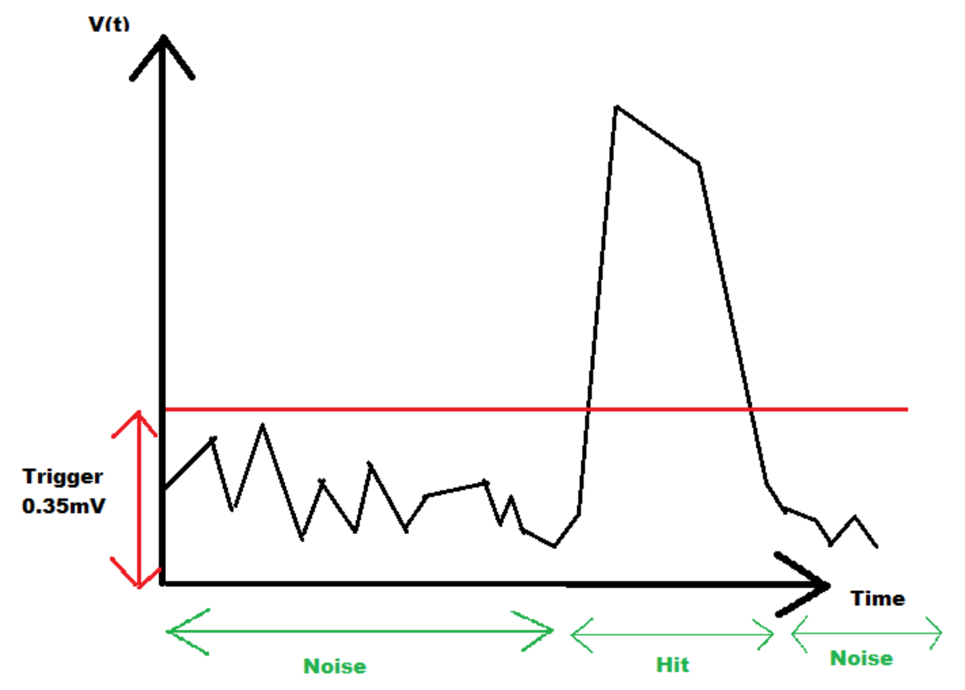
The trapezoidal algorithm



The high voltage

Means of data acquisition and their functionning

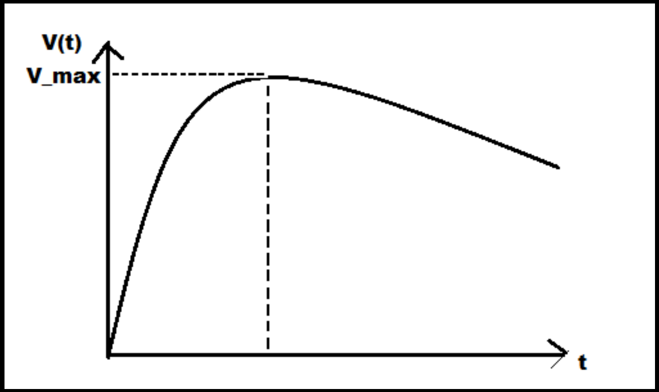
The trigger is the threshold for which the software considers that the element detected is a photon.

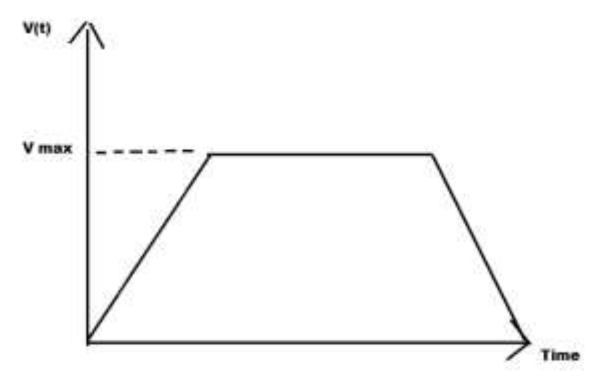


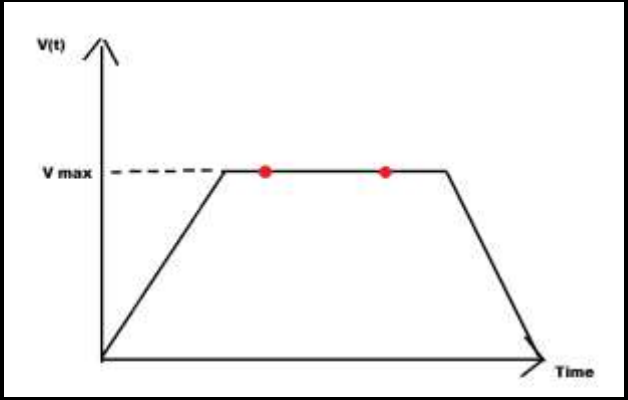
We found a threshold value of 0.35mV to ignore the noise.

Means of data acquisition and their functionning

What is the trapezoidal algorithm?







Take the voltage curve as a function of time.

→

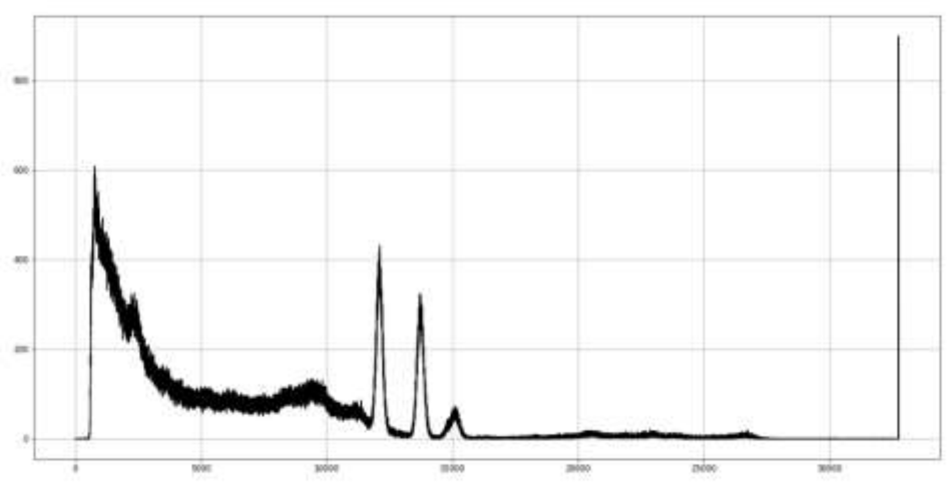
Correct the decay time and make a sliding average.

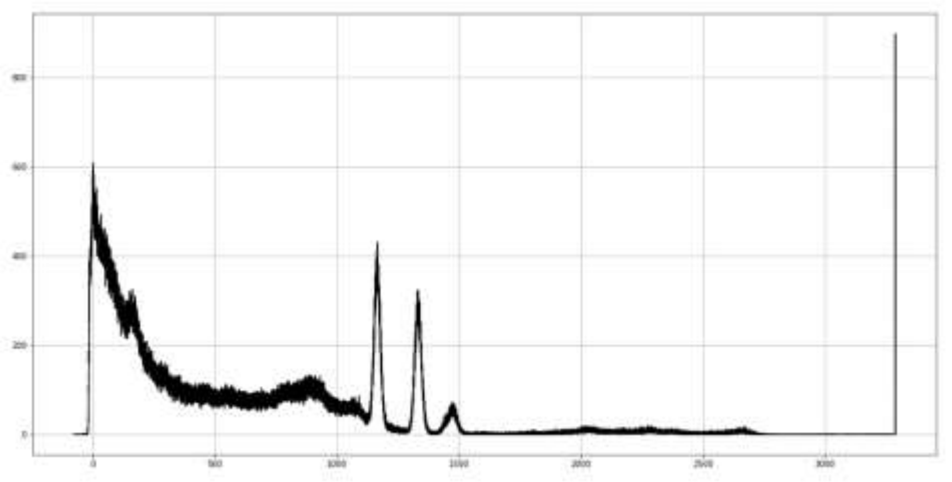
→

Make an average between two points of the trapezoid.

Means of data acquisition and their functionning

For the calibration we switch from a channel histogram to an energy histogram.



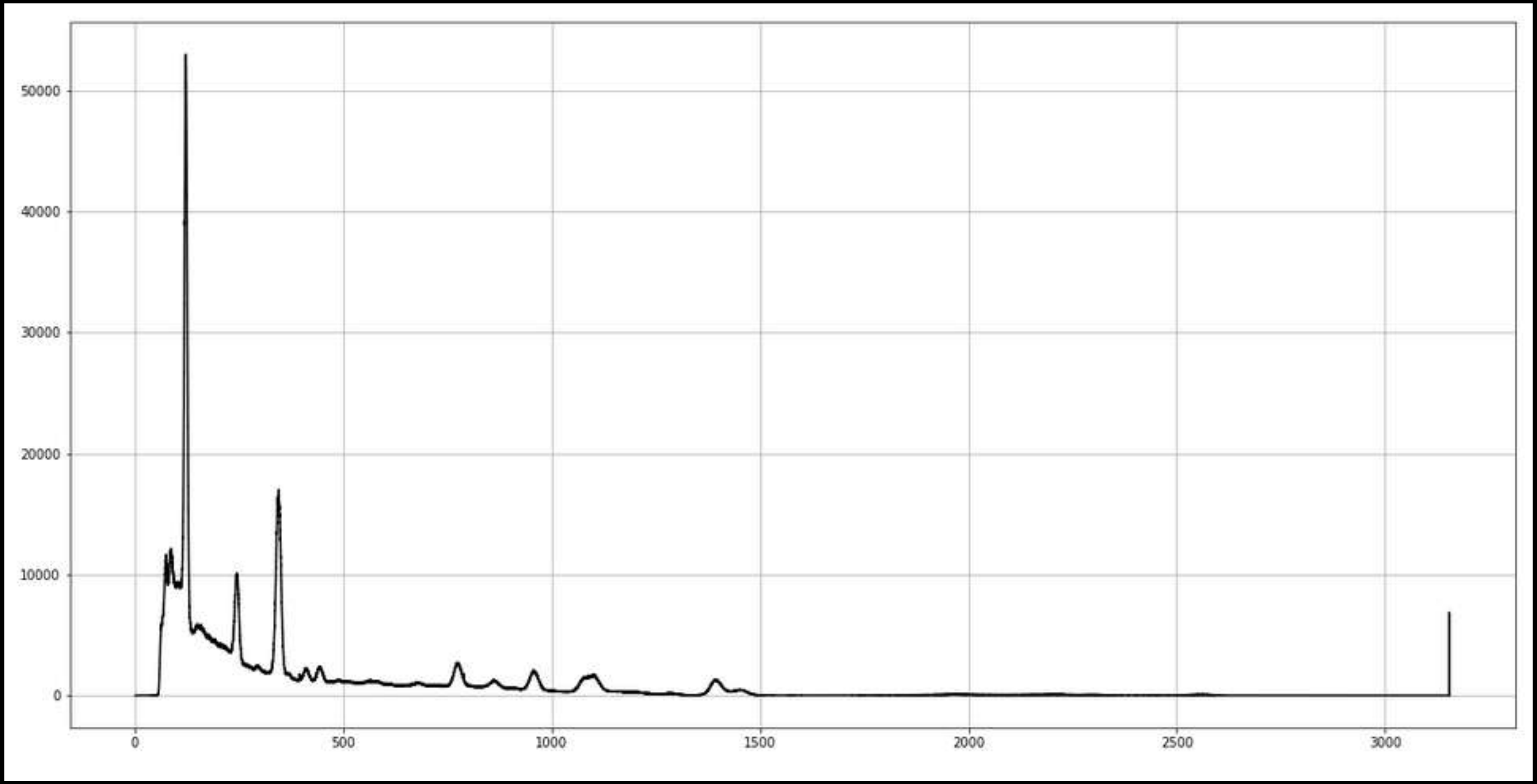


The two gamma peaks of Cobalt correspond here to 12500 and 14000 « channels ».

Either, 1330 and 1170 keV after calibration

Calibration equation: energy = a*channel + b

Means of data acquisition and their functionning



Once the calibration is done, we can change the source, take something other than Cobalt and look at the energy peaks of this new source. For example, here, the calibration allows us to see the different peaks of the Europium.

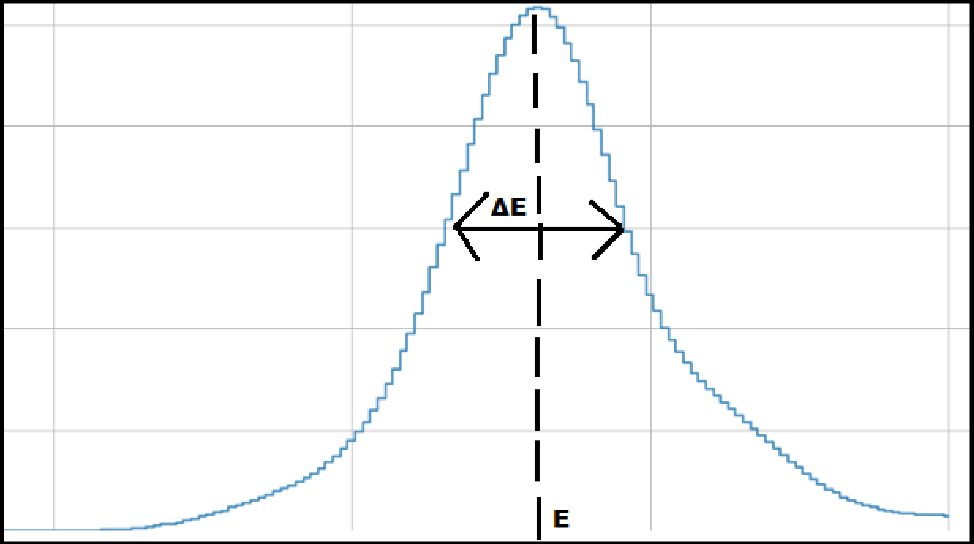
Means of data acquisition and their functionning

The resolution gives us the width of the peaks as a function of the energy of these peaks.

The resolution formula is :

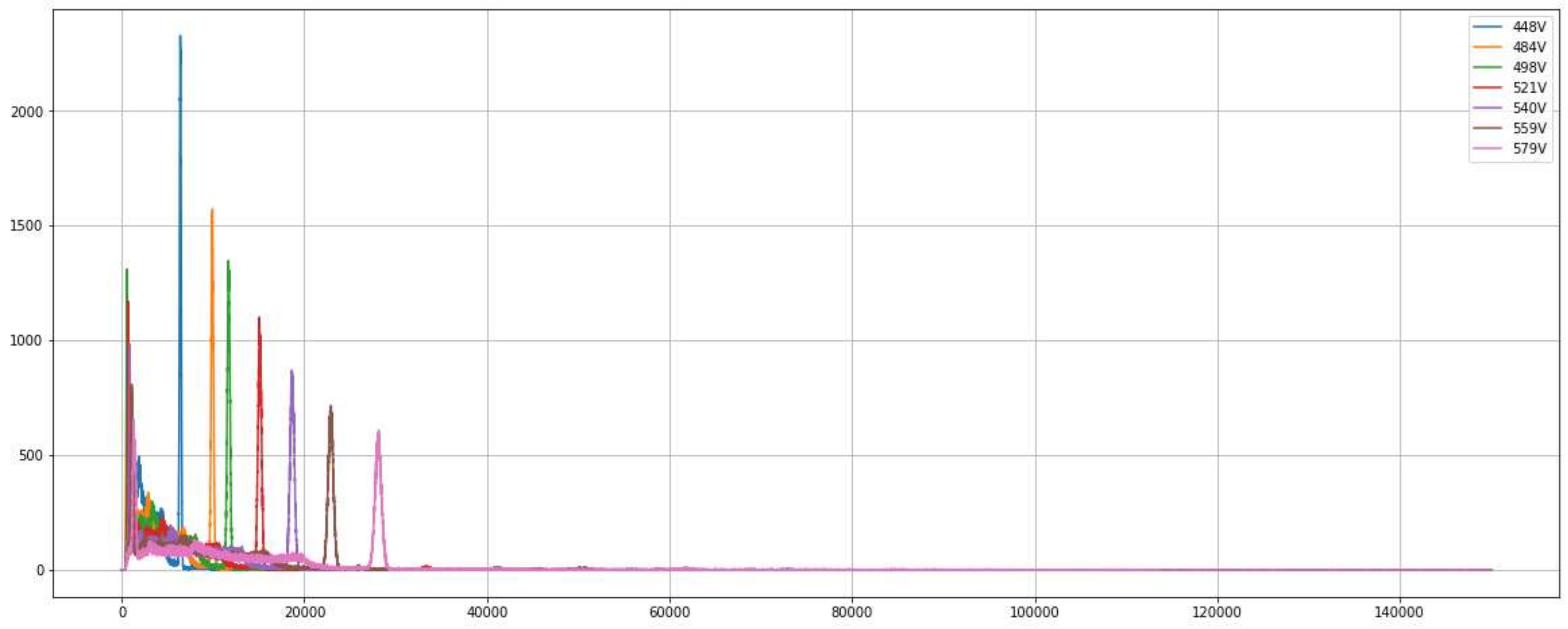
$$\frac{\Delta E}{E}$$

where ΔE is the width of the peak and E the energy of the peak



If the width of the peaks is very small, the margin of error is also very small.

Means of data acquisition and their functionning

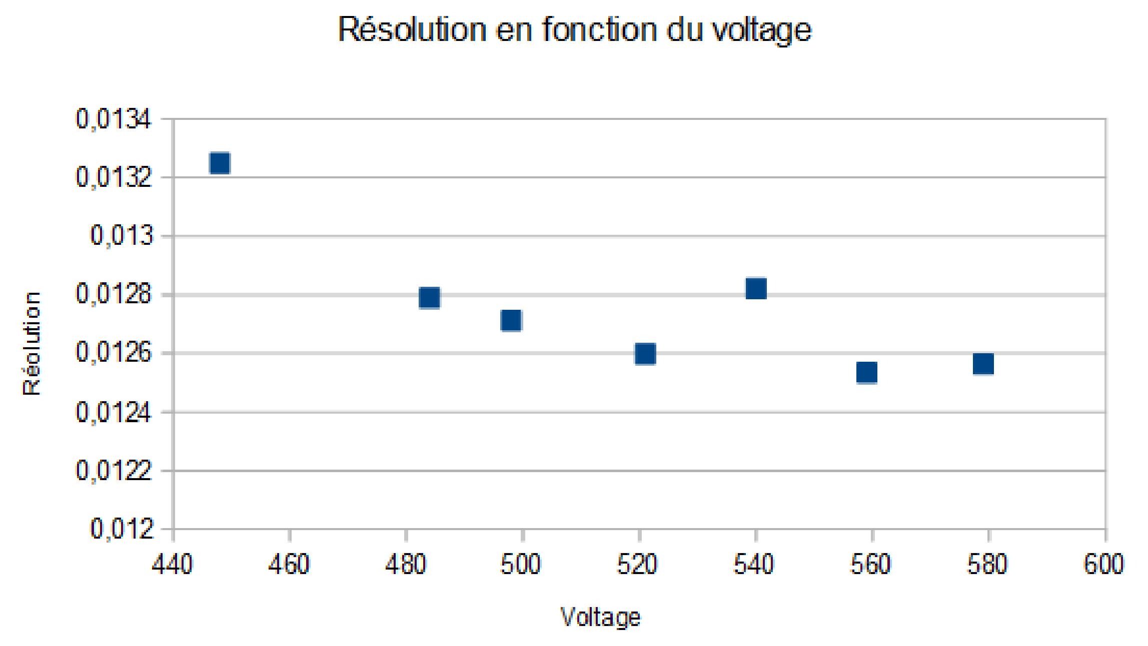


I used Cesium which has a peak at an energy of 662 keV and I calculated its resolution for different high voltages (from 448V in blue to 579V in pink).

Means of data acquisition and their functionning

Table of resolutions according to high voltage :

High Voltage (V)	Resolution
448	0,0132491034
484	0,0127894943
498	0,012711991
521	0,0125981732
540	0,0128214465
548	0,0125345483
579	0,0125634184



We can see that for a high voltage of 548V we have the lowest resolution. This is the high voltage value we will use for the rest of this internship.

Means of data acquisition and their functionning

The last parameter is the efficiency, this is the product of the geometric efficiency and the intrinsic efficiency.

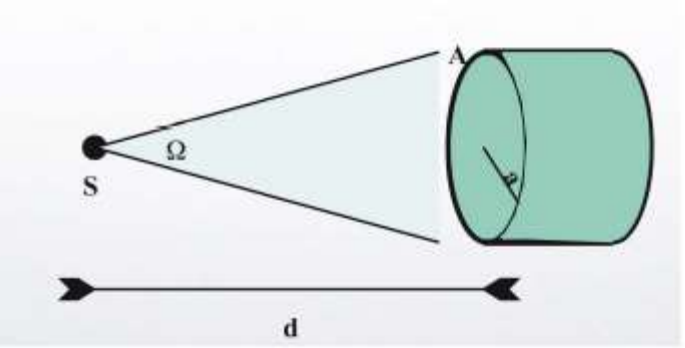
$$\epsilon_{abs} = \epsilon_{int} * \epsilon_{géo}$$

The absolute efficiency is the ratio of the number of elements detected to the number of elements emitted.

$$\epsilon_{abs} = \frac{number\ of\ events\ detected}{number\ of\ events\ emitted}$$

The geometric efficiency is the ratio between the solid angle and 4π

$$\epsilon_{géo} = \frac{1}{2}[1 - \frac{d}{\sqrt{d^2 + a^2}}]$$



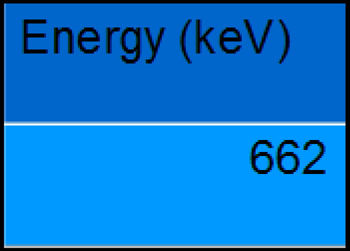
Our experiments with the detector and the results obtained

LaBr3 scintllation detector.

NaI scintllation detector.

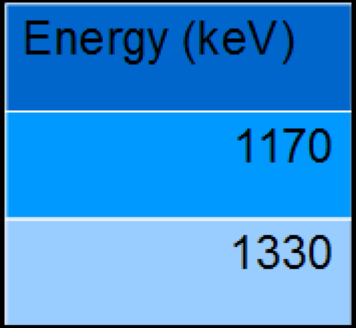
Our experiments with the detector and the results obtained

The β^- decay of Cesium creates a peak of 662keV.



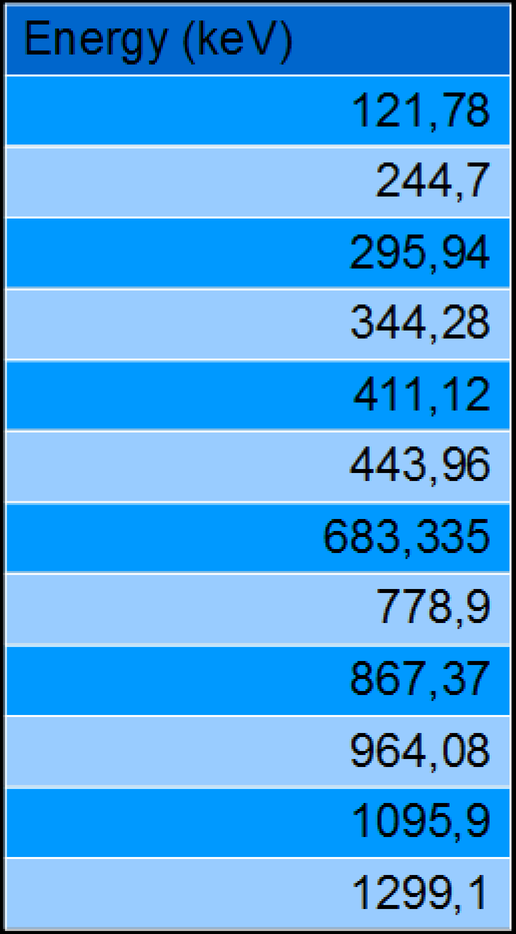
Energy (keV)
662

The β^- decay of Cobalt creates two peaks of 1170 and 1330keV.



Energy (keV)
1170
1330

The β^- decay of Europium creates a good ten.

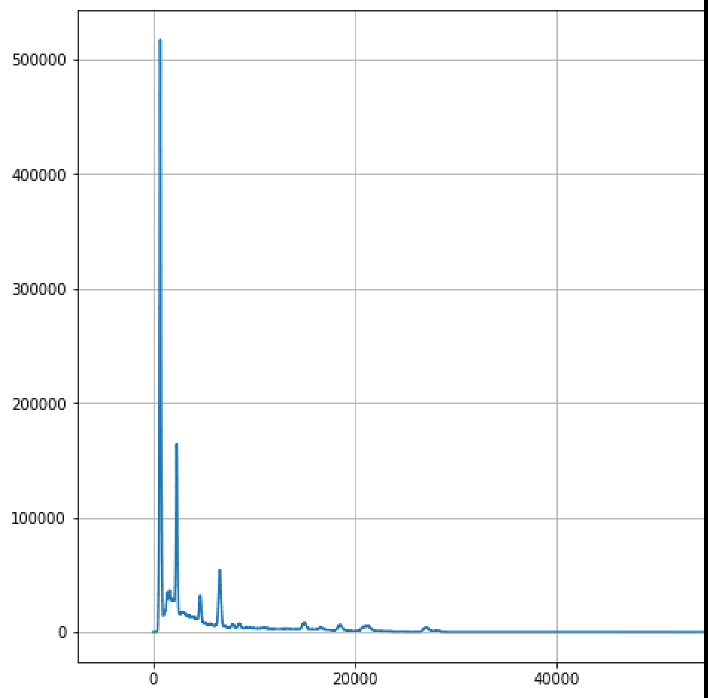


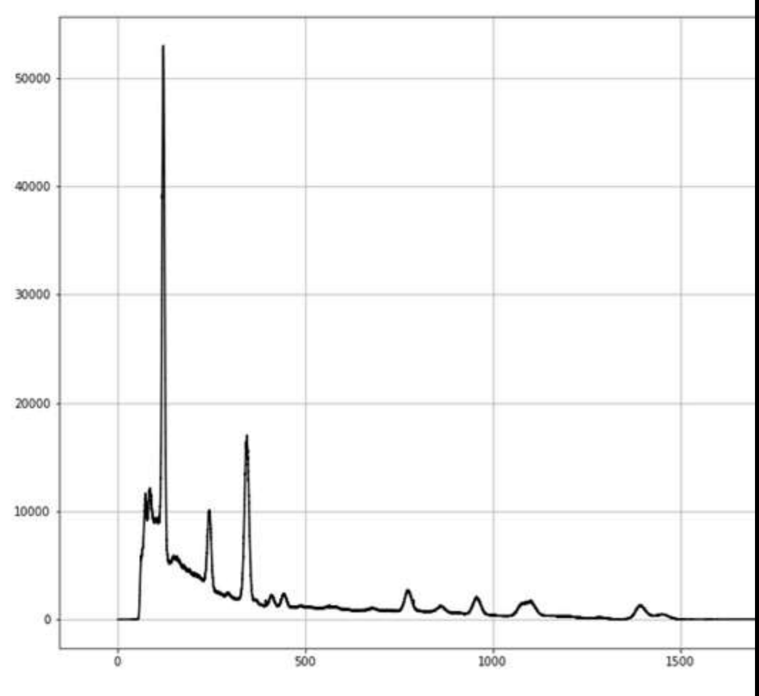
Energy (keV)
121,78
244,7
295,94
344,28
411,12
443,96
683,335
778,9
867,37
964,08
1095,9
1299,1

Our experiments with the detector and the results obtained

Thanks to this affine function:

Energy = 0.0615521423*channels+0.67672271





We can calibrate and find the energy spectrum of our sources (here, Europium and its numerous peaks)

Our experiments with the detector and the results obtained

And finally, after the calibration, it was also necessary to make the absolute efficiency and to deduce then the intrinsic efficiency with the help of this relation.

$$\epsilon_{abs} = \epsilon_{int} * \epsilon_{géo}$$

For the absolute efficiency it is enough to take the number of hits received in a peak divided by the number of hits it should have received.

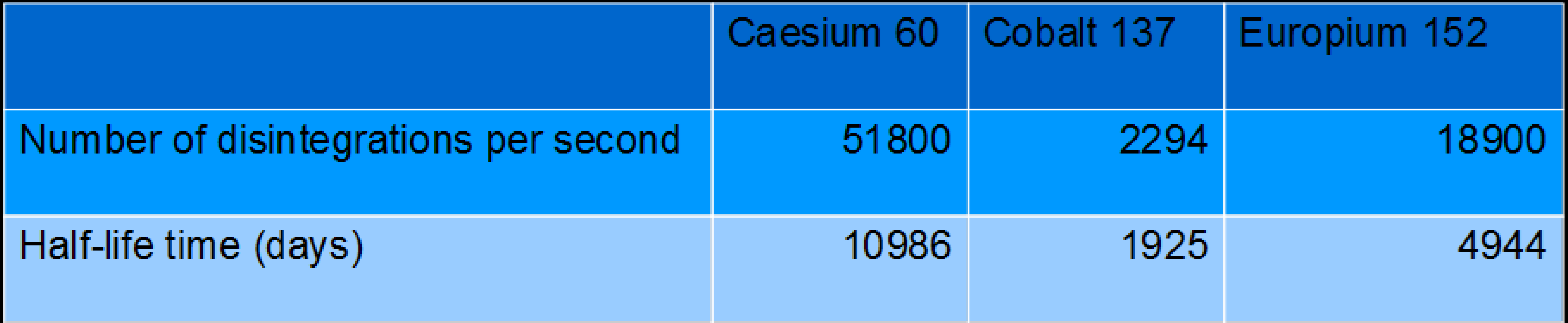
$$\epsilon_{abs} = \frac{number\ of\ events\ detected}{number\ of\ events\ emitted}$$

Our experiments with the detector and the results obtained

The number of hits it should have received is calculated using the number of disintegrations per second A(t), with this relation :

$$A(t) = A(0)2^{-\frac{t}{\tau}}$$

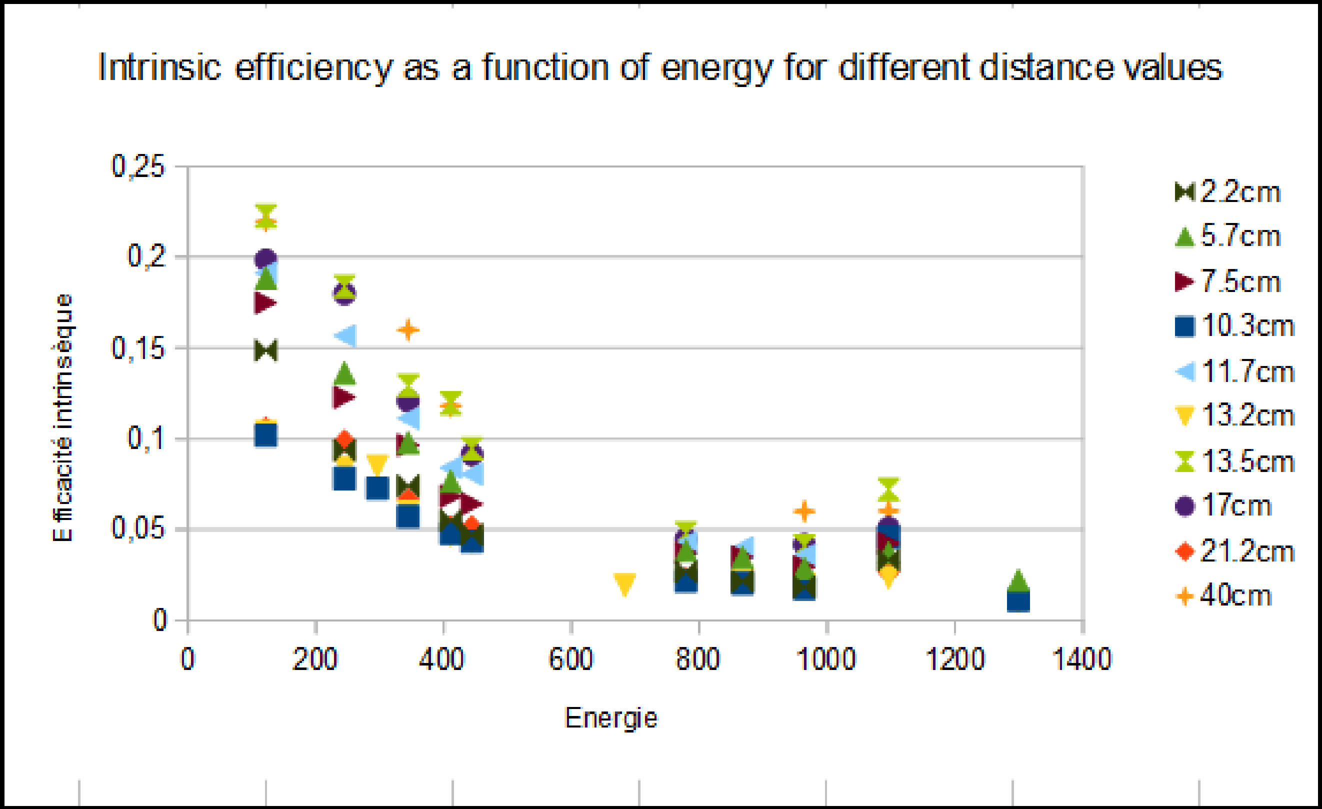
Where A(0) is number of disintegrations per second at the origin of the source, t is the time between the origin of the source and today and τ the half-life time.



	Caesium 60	Cobalt 137	Europium 152
Number of disintegrations per second	51800	2294	18900
Half-life time (days)	10986	1925	4944

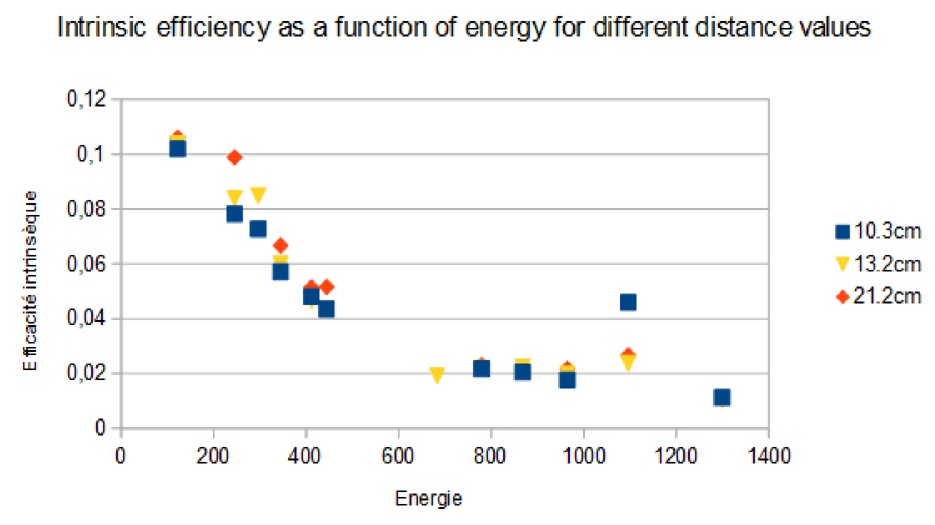
Our experiments with the detector and the results obtained

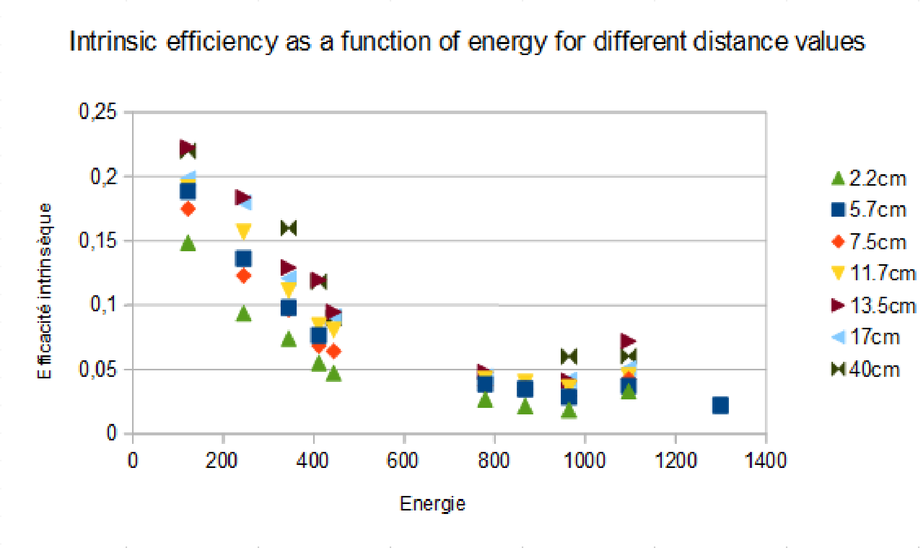
We also verified that the intrinsic efficiency did not vary with the distance between the source and the detector. Indeed we can see on the graph that the intrinsic efficiencies as a function of energy are very similar regardless of the distance.



Our experiments with the detector and the results obtained

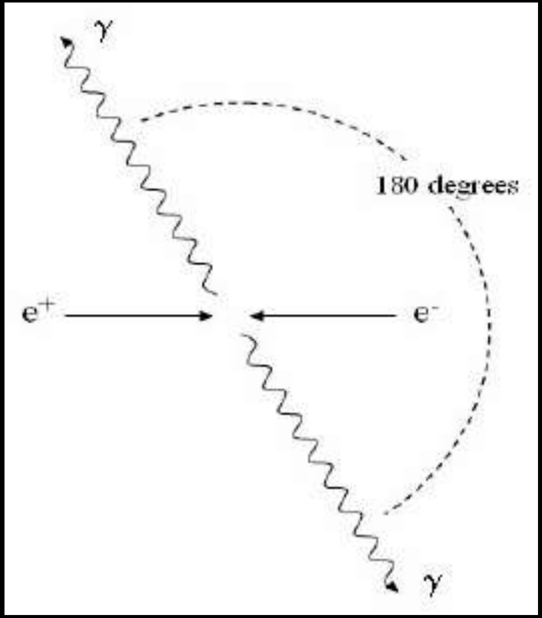
There are two separate graphs corresponding to two different measurement days. It can also be seen that in addition to not changing with distance, the intrinsic efficiency changes with energy. LaBr3 is more efficient at low energies.





Our experiments with the detector and the results obtained

The semi-conducting Germanium detector, which is another type of detector than the scintillation detector, with which measurements can be made with LaBr3.



Positron-electron annihilation which will give two opposite gammas which can then be detected by our detectors.

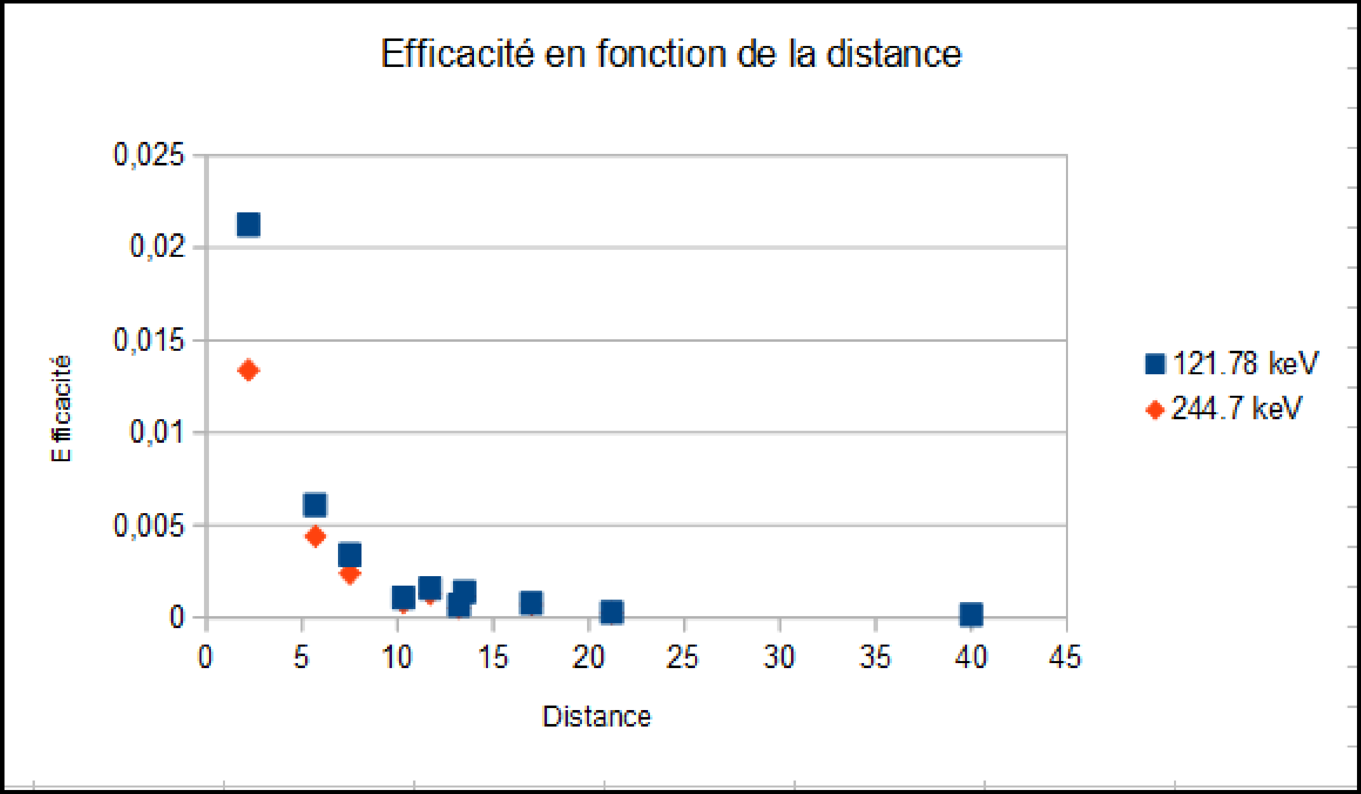
Conclusion

- I) We were able to understand the operation of detectors and in particular those with scintillations such as LaBr3.

- II) We tried to get the best gamma histogram by changing the trigger, the trapezoidal algorithm and the high voltage.

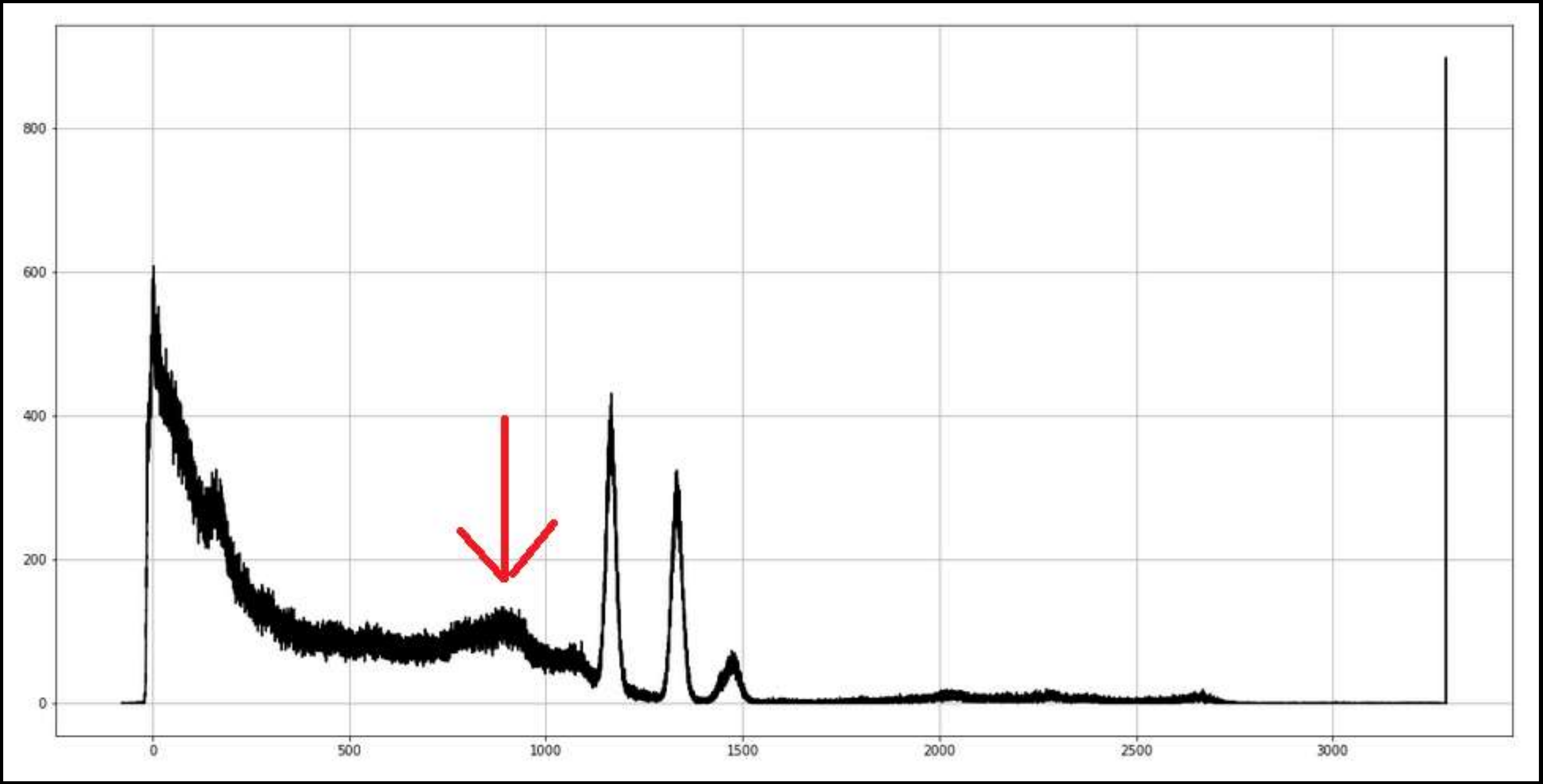
- III) We calibrated, tried to find the best possible resolution and calculated the efficiency of our

Annex



The absolute efficiency as a function of distance for two energy values. It can be seen here that the efficiency decreases as the distance increases. This is normal as the geometric efficiency decreases.

Annex



We can see here a small peak before the two energy peaks of the Cobalt. It is a peak called the Compton front which is due to the fact that the gamma which arrives on the photocathode does not necessarily produce an electron by photoelectric effect but possibly an electron by Compton effect, thus an electron of lower energy.
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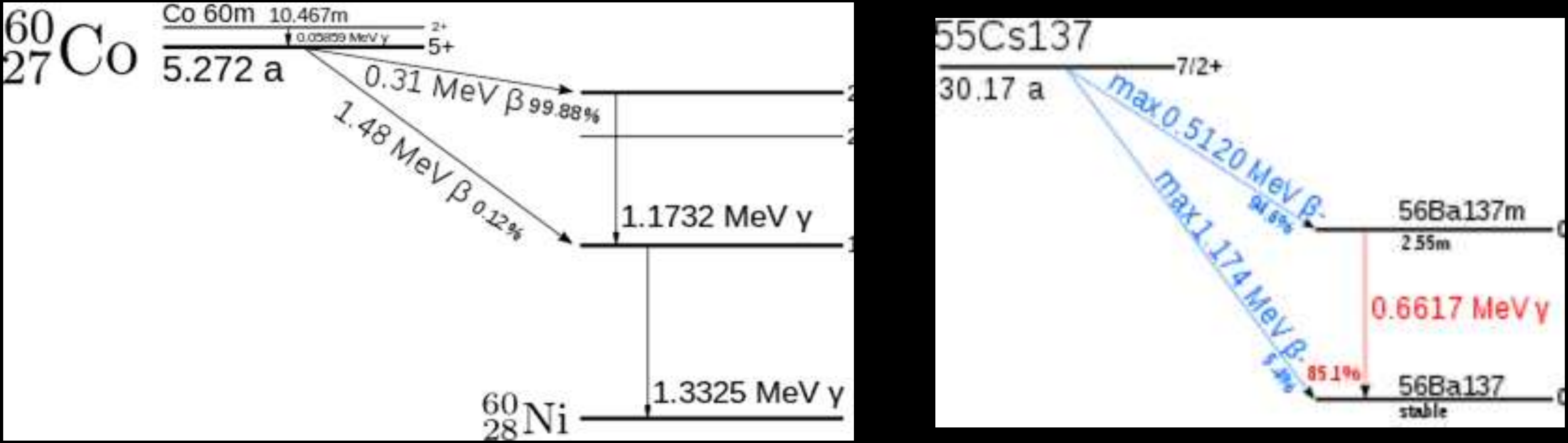
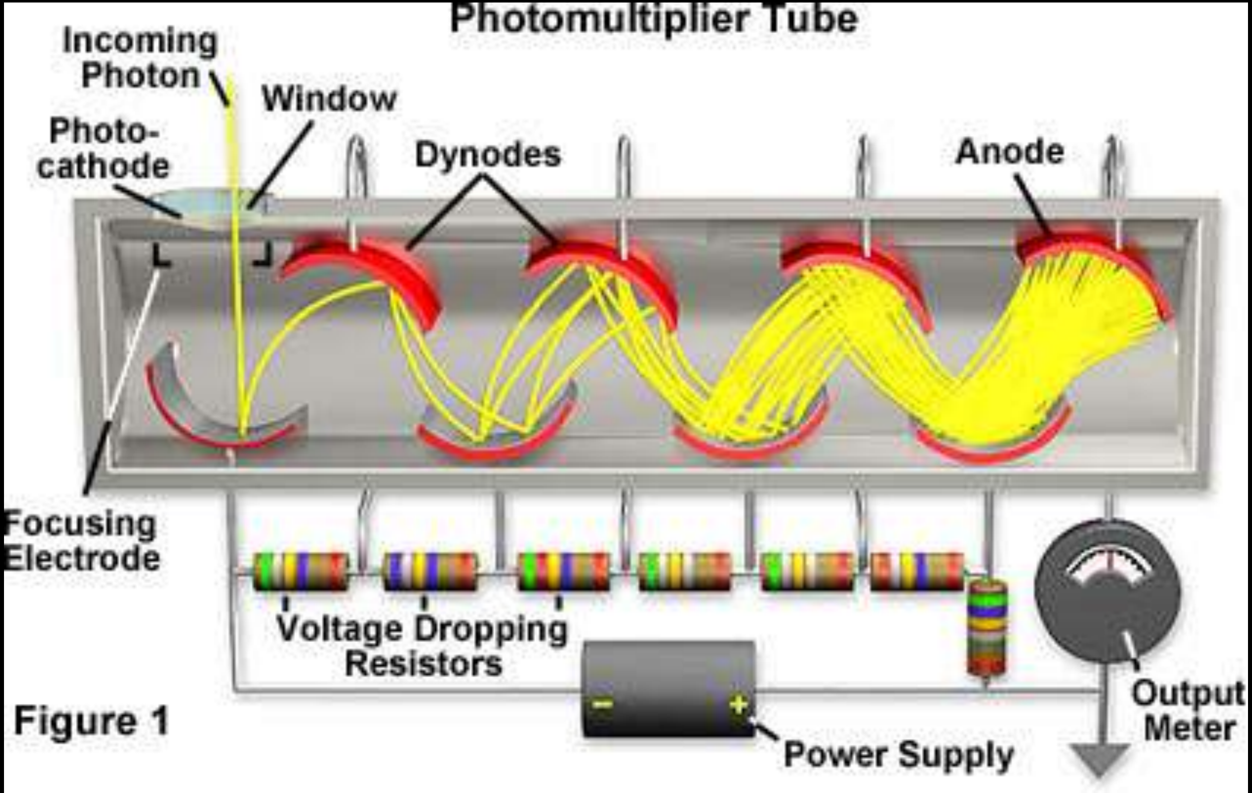
Annex



Cobalt 60 and Cesium 137 decay diagram.

Annex



Operation of a photomultiplier tube