Contents

1 Introduction

This experiment is intented to introduce you to some of the measurement methodes in particle and nuclear physics. The detectors used in the experiment are scintillators. We will use two different types of them, an inorganic and an organic scintillator, and have a look at their characteristics. As an application we will make an energy- and a time measurement.

The first part introduces the two types of scintillators: how their signals look like, what are the differences between the organic and the inorganic ones. You will assemble a plastic scintillation detector on your own, giving you the possibility to look at the single parts of the detector.
Then we work with the inorganic scintillation counter, a NaI scintillator, and performing energy measurements. After calibrating the detector you will determine the endpoint energy of the radiation of a ^{90}Sr source.
In the third part you use organic scintillators for some time- and coincidence measurements. As an application of the coincidence technique you detect cosmic muons and measure the dependence between their rate and their angle of incidence.

2 Theory

2.1 Radiation

2.1.1 γ radiation

γ radiation occurs mostly as consequence of a previous β- or α- decay. When the resulting core fades into it's ground state it emits γ- radiation. The energy of the radiation is the same as the energy of the transition. The theoretical γ- spectrum is a discret spectrum.

2.1.2 β radiation

The β-decay is a three-particle-decay. A neutron decays into a proton, an electron and an electron-antineutrino.

$$n \rightarrow p + e^- + \bar{\nu}$$

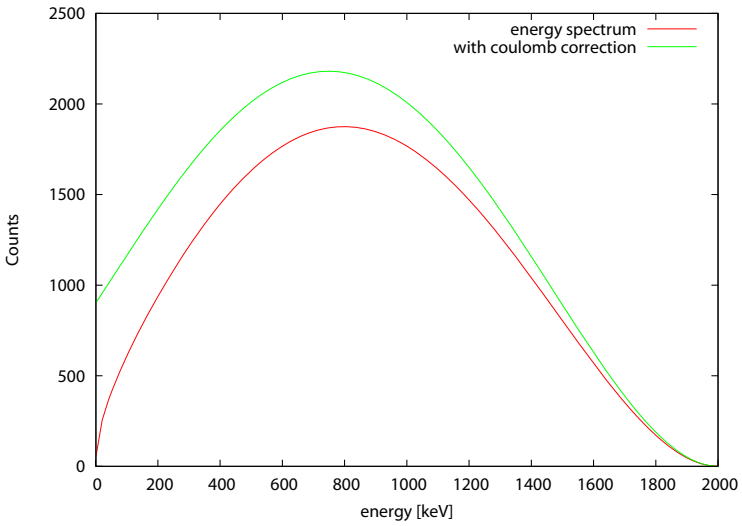


Figure 1: Theoretical β-spectrum of 2MeV electrons

The β- spectrum is continous until the endpoint energy E_{max}, as it follows from Fermi's "golden rule":

$$\lambda = \frac{1}{\tau} = \frac{2\pi}{\hbar} \int |H_{fi}|^2 \, \delta(E_f - E_i) ds$$

(The deduction of this formula is to be found in the appendix.) It follows for the counts per energy device:

$$\frac{\mathrm{d}N}{\mathrm{d}E} \propto F(Z,E) \cdot (E + mc^2) \cdot \sqrt{E^2 + 2Emc^2} \cdot (E_{max} - E)^2$$

$F(E,Z)$ is the Fermi-Function. It is a correction factor to allow for the Coulomb interactions of the electrons with the nuclear charge, which slows down the emitted electrons and accelerates the emitted positrons. Therefore the Fermi-Function depends on the nuclear charge number and the energy of emitted particles.

$$F(E,Z) = \frac{2\pi\eta}{1 - e^{-2\pi\eta}}$$

In the case of $\beta^{\pm}$-decays $\eta = \mp \frac{Ze^2}{4\pi\epsilon_0 \hbar c \beta_e} = \mp \frac{Z\alpha}{pc}$ here $\beta_e = \frac{p_e c}{E_e}$ is the velocity of the electron in units of c and α the fine-structure constant.

Kurie-Plot If we plot $\sqrt{\frac{\frac{\mathrm{d}N}{\mathrm{d}E}}{F(Z,E) \cdot (E+mc^2) \cdot \sqrt{E^2+2Emc^2}}}$ against the kinetic energy E we get the Kurie-Plot. For allowed transitions it is a linear plot which cross the energy-axes in E_{max}, the maximal energy of the electrons. With this diagram we can extrapolate to maximal energy of our β-source quite accuratly.

2.1.3 Cosmic muons

Muons are elementary particles, they are classified as leptons. Like electrons they have got a electric charge, but they are 207 times heavier than electrons ($m_e = 511\mathrm{keV}$) and unstable. They have got a mean lifetime of 2,19 μs.
Cosmic radiation consists of high energy protons, in the upper atmosphere they collide with molecules and pion and kaons accure.

$$\begin{aligned} p + p &\rightarrow p + n + \pi^+ \\ p + n &\rightarrow p + p + \pi^- \\ p + p &\rightarrow p + \Lambda + K^+ \end{aligned}$$

They are unstable and decay amongst others into muons.

$$\begin{aligned} \pi^+ &\rightarrow \mu^+ + \nu_\mu \\ \pi^- &\rightarrow \mu^- + \bar{\nu}_\mu \\ K^+ &\rightarrow \mu^+ + \nu_\mu \end{aligned}$$

Because of they are highly relativistic cosmic muons can reach earth's surface before they decay, when they reach the surface they got energies up to 1 GeV. The rate of cosmis muons on sea level is about 100 $\frac{particles}{m^2 \cdot s}$.

2.2 Interaction of particles with matter

2.2.1 Photons

The intensity reduction of electromagnetic radiation in matter is exponential. If photons with an intensity I_0 pass through a material with a mass absorption coefficient μ and thickness x, the intensity of the outcomming photons is given by

$$I(x) = I_0 e^{\mu x} \qquad with \qquad \mu = \sigma \frac{N_A}{A} \rho$$

Here σ is the cross section, N_A Avogadro's number and A the molar mass of the material. There are three different types of photon-interaction in matter: the photoelectric effect, the compton effect and pair production.

Photoelectric Effect At energies lower than 100 keV the photoelectric effect is the dominant one. If the energy of the photon E_γ is higher than the bound energy E_b of the electron it can be absorbed by the electron. The outcome of this is a free electron with an energy of $E_e = E_\gamma - E_b$ and a hole in the atomic shell.
The cross section of the phototelectric effect depends on the atomic number Z and on the energy of the photon E_γ

$$\sigma_{pe} \propto \frac{Z^5}{E_\gamma^{7/2}}$$

Compton effect The Compton effect is the scattering of a photon with an electron. It is the dominant effect at energies of about 1 to 2 MeV. The photon transfers a part of its energy and momentum to the electron. If the energy of the photon is high with respect to the bounding energy of the electron the electron can be accounted as a free electron. From the four-momentum we can determine the energy loss of the photon.

$$\frac{1}{E'_\gamma} - \frac{1}{E_\gamma} = \frac{1}{m_e c^2}(1 - cos\vartheta)$$

The energy transfer to the electron is maximal when the photon is back scattered, so $\vartheta = \pi$. If we approximate $E_\gamma \ll m_e$ we get the maximal kinetic energy of the electron, the so called Compton edge energy:

$$E_{kin,max} = E_\gamma - E'_\gamma = E_\gamma \left(1 - \frac{m_e c^2}{2E_\gamma}\right)$$

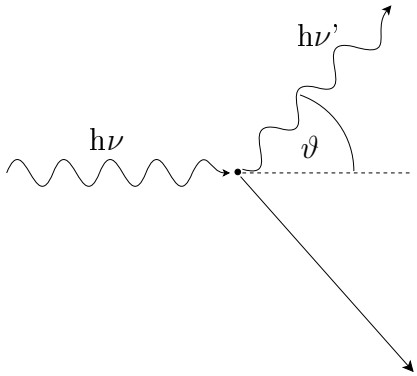


Figure 2: Kinematics of Compton scattering

Pair creation If the energy of the photon is high enough pair creation can take place. The rest mass of two electrons and the backstroke energy at the nucleus is required, so the photon needs to exceed a threshold value of:

$$E_\gamma \geq 2m_e c^2 + 2\frac{m_e^2 c^2}{m_{nucleus}}$$

For high energies the cross section of pair creation is given by:

$$\sigma_{pair} = \frac{7A}{9N_A X_0}$$

where X_0 is the distance in which the energy is reduced to a fraction of 1/e. Pair creation dominates the energy loss of γ radiation for energies from 5MeV and above.

For high energies of the incomming photon electro-magnetic shower can occure. They consist of electrons, positrons and photons which are produced by interactions with matter and have enough energy to start further interactions.

The total absorption coefficient is the sum of the coefficients of the single processes.

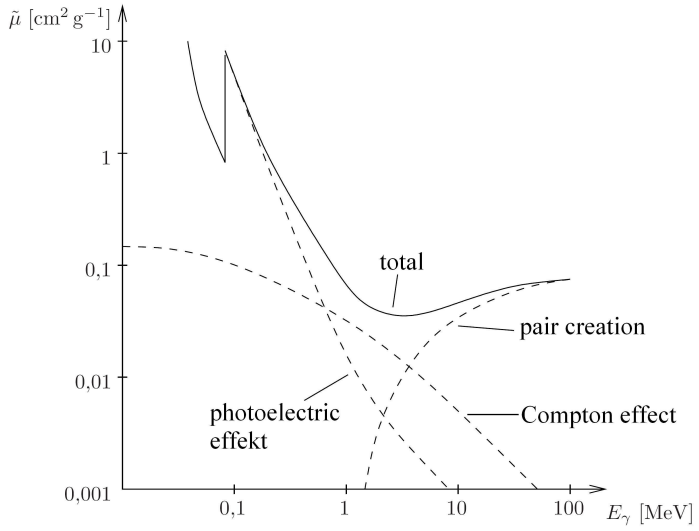


Figure 3: Total absorption coefficient for γ radiation in lead

2.2.2 Charged particles

If charged particles travers through matter different processes of interactioin can take place: ionisation, Cherenkov radiation or the particle can cause the emission of transition radiation.

Ionisation The Bethe-Bloch formula gives the energy loss by ionisation per distance for "heavy" particles:

$$-\frac{dE}{dx} = \frac{4\pi N_A r_e^2 m_e c^2 z^2 Z}{\beta^2 A}[ln(\frac{2m_e c^2 \beta^2}{(1-\beta^2)I}) - \beta^2]$$

where z is the charge of the incoming particle in units of the elementary charge; Z and A the atomic number and the nuclear number of the absorption material; m_e the electron mass; r_e the classical electron radius; N_A Avogardo's number and I a material constant (approximately $I = 16Z^{0.9}eV$). The energy loss depends basically on the density of the material, it is independent from the mass of the particle. Energy loss by ionisation is a statistical process, particles interact very often before they emit their whole energy, the Bethe-Bloch formula describes the mean energy loss.

Cherenkov radiation Cherenkov radiation occures if the velocity of a charged particle passing through matter is higher than the velocity of light

in the medium. The particle emits a characteristic electro-magnetic radiation. Atoms near the track are temporarily polarized, so they become electric dipols and emit electromagnetic radiation because of the change in the dipol field in time.
The energy loss by Cherenkov radiation is given by:

$$\frac{1}{\rho}\frac{dE}{dx} \approx 0.5 \frac{keVcm^2}{g}$$

Cherenkov radiation is useful for the detection of light particles.

Bremsstrahlung Fast charged particles loose energy by interaction with the coulomb field of nuclei of the medium. If the particles get slowed down in the coulomb field they loose theire kinetic energy by emitting photons, this is the so called Bremsstrahlung. The energy loss by Bremsstrahlung is given by:

$$-\frac{dE}{dx} = 4\alpha \cdot N_A \frac{Z^2}{A} \cdot z^2 (\frac{1}{4\pi\epsilon_0}\frac{e^2}{mc^2}^2 \cdot E \cdot \ln\frac{183}{Z^{1/3}})$$

where m is the mass of the particle.

Bremsstrahlung is only relevant for electrons. The energy loss for electrons is given by:

$$-\frac{dE}{dx} = \frac{E}{X_0}$$

For the ratio energy loss by Bremsstrahlung to energy loss by ionisation holds:

$$\frac{\frac{dE}{dx}_B}{\frac{dE}{dx}_I} = \frac{ZE[MeV]}{580}$$

2.3 Scintillator detector

The scintillator is one of the most commonly used detector in particle physics. It makes use of the fact that certain transparent materials emit a flash of light when ionising particles travers it. The number of photons emitted is proportional to the energy loss by ionisation of the charged particle.
There are two different types of scintillators: the inorganic crystal scintillator and the organic scintillator (e.g. plastic scintillator), both of them will be used in this experiment.

2.3.1 Inorganic Scintillators

Inorganic scintillaors are mostly used for energy measurements. They are ionic cristalls doped with activator centers. The material used in our experiment is NaI(TI), a Natriumiodid cristall with a Thallium activator.
The mostly used crystals are insulators, their valence band is fully occupied but the conduction band is empty. The energy difference between the two bands is about 5 to 10 eV, for producing extra energy levels between the valence and the conduction band, activator centers are added to the cristall. Incoming charged particles or photons lift electrons from the valence band up to the conduction band, where they can move freely. By the use of this electron-hole-pairs the crystal gets a certain conductivity. If the free electron recombines with a hole, the released energy can be emitted as a photon.

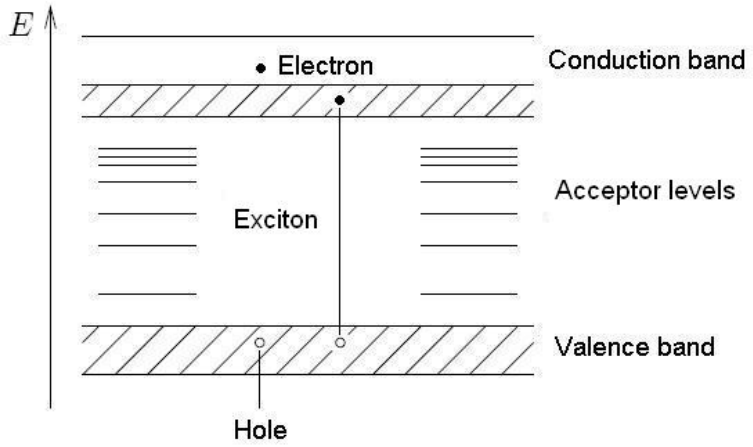


Figure 4: Energy band in inorganic scintillating crystals

2.3.2 Organic Scintillators

The most distinguishing feature of organic scintlillators is a very rapid decay time. Because of this fact, they are ideal for time measuerments. Organic scintillators can be fluid- or plastic scintillators, so they can easily be produced in nearly every geometry.
The production of photons in plastic scintillators is a molecular process. A fluoresent substance is activated by the energy loss of a particle. At the passage from the excited state to the ground state ultra-violet light is emitted. Because the substance is not transparent for it is own light, a second substance is added. This so called wavelength shift absorbs the emitted ultra-violet light and reemits it again in a wavelenght which can be detected by a photomultiplier.

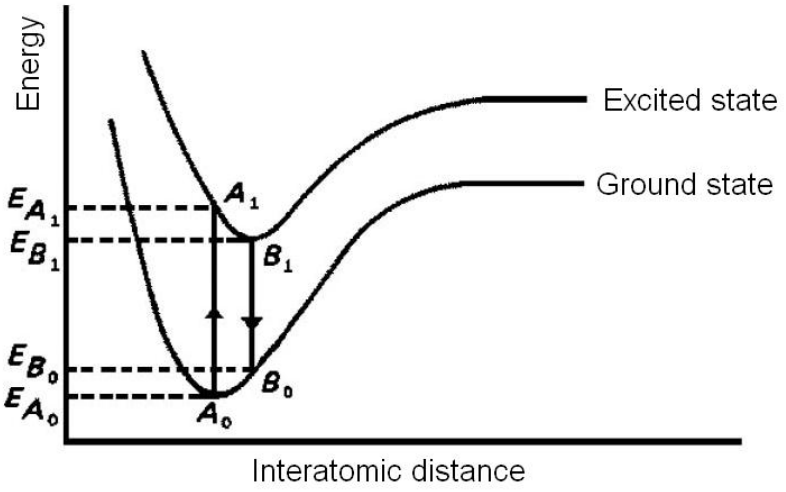


Figure 5: Energy band in organic scintillators

2.3.3 Lightguides

Light produced in scintillator has to be transmitted to the photomultiplier, this is done by lightguides. Lightguides have a special shape so that the light is passing through by total reflection on the surface.

2.3.4 Photomultiplier

The instruments used for registrating fast light signals are photomultipliers. Electrons are emitted from an alkalimetal-photocathode by photo electric

effect from visible light coming from a scintillation counter. These electrons are accelerated by an electric field to the first dynode, which is part of a multiplying system.

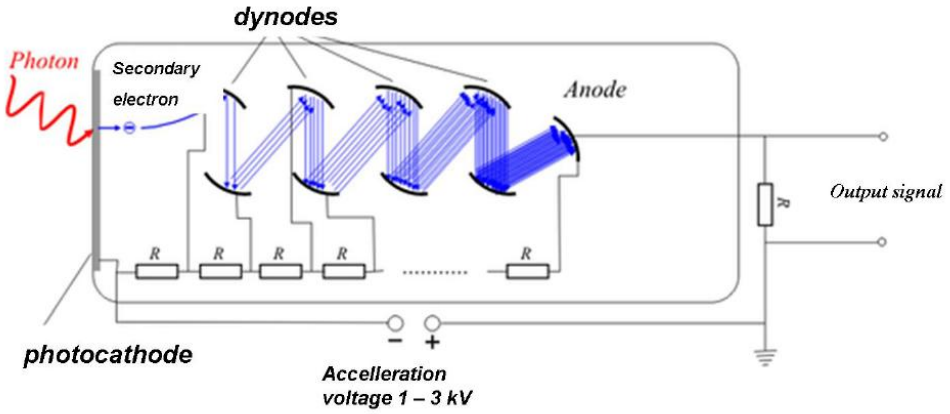


Figure 6: Photomultiplier

The amplification factor of a photomultiplier depends on the number of dynodes in the multiplier and the secondary emission factor δ, which is a function of the energy of the primary electron. The energy of the electrons on each dynode is a function of the potential difference V between the dynodes. If N is the number of stages in the photomultiplier and K is a proportionality constant we can write for the gain G:

$$G = \delta^N = (KV)^N$$

2.4 Coincidence measurements

The coincidence method is a technique often used in nuclear physics to gain insight the details of a reaction or a decay. It accounts the simultanious occurence of two events. Simultanious in this context means within a finite time intervall that is short the time resolution. We will use the coincidence methode to detect cosmic muons passing through two scintillators in a coincidence circuit.

2.4.1 Accidental coincidences

By making coincidence measurements we have to consider the possibility of "accidental coincidences" which can occur from uncorrelated background

events in the detector.
The rate of accidental coincidences can be calculated from the singles rates of each scintillator with the given formula:

$$Accidental \cong \sigma N_1 N_2$$

Here N_1 and N_2 are the single counting rates from each detector and σ is the time period in which two signals are considered as coincident.

3 The experiment

3.1 Sources used in the experiment

We use three different radioactive sources which are commonly used in nuclear and particle physics as "calibration sources" and for tests of paticle detectors.

3.1.1 ^{137}Cs

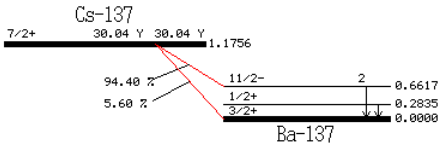


Figure 7: Decay scheme of ^{137}Cs

Caesium 137

$E_e = 0.51397$ MeV
$E_\gamma = 0.66166$ MeV

half-lifetime: 30.07yr

3.1.2 ^{60}Co

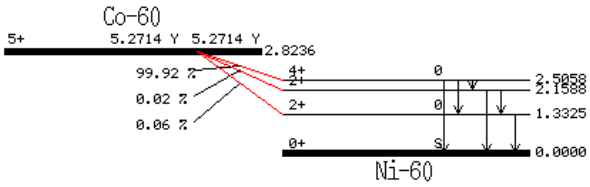


Figure 8: Decay scheme of ^{60}Co

Cobalt 60

$E_e = 0.318$ MeV

$E_{\gamma 1} = 1.1733$ MeV
$E_{\gamma 2} = 1.3325$ MeV

half-lifetime: 5.2714yr

3.1.3 ^{90}Sr

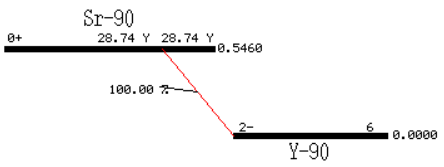
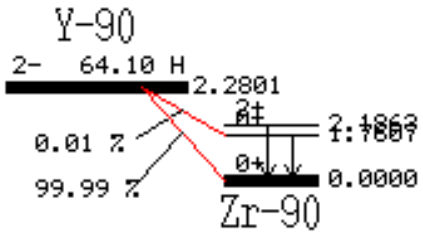


Figure 9: Decay scheme of ^{90}Sr

Strontium 90

$E_e = 0.5460$ MeV

half-lifetime: 28.74yr



Yttrium 90

$E_e = 2.2801$ MeV

half-lifetime: 64.1h

Figure 10: Decay scheme of ^{90}Y

3.2 Equipment used in the experiment

3.2.1 High voltage unit

The high voltage needed is given on each scintillator. Take care that you choose the right polarity.

The two setups F80 and F81 have different types of high voltage units.

- F80
  Be careful that you choose the right polarity of the voltage, the organic scintillators have to be run with a negative, the inorganic scintilltors with a positive polarity. Never change the polarity when the high voltage is switched on. Turn it off before you connect or disconnect a scintillator.

- F81
  F81 has got three high voltage units each with a preset polarity. Be careful to use the high voltage units with positive polarity for the inorganic and the units with negativ polarity for the organic scintillators. Turn off the voltage before you connect or disconnect a scintillator.

3.2.2 Data taking program

Most important features of the program:

- Take a spectrum:
  Datei → *Datenquelle öffnen...* Choose either *Detektor* for making a new measurement or *Datei* to read from a saved data file.

- Measuring settings
  Click on *VKA* → *Messung-Vorwahl...* and choose your measuring settings. You can predefine the measurement time, the number of channels etc. Do not change the number of channels in-between your measurements, it will change the calibration factor!

- Correct a spectrum
  Open your spectrum and click *Optionen* → *abziehen* choose the background spectrum from your data.

- Save your spectrum
  It is advisible to save every spectrum directly after the measurement before manipulating it! Click on *Datei* → *Sichern unter...* and choose a file format. If you want to save the normal spectrum choose a CNF-file for making a Kurie-plot you have to save it as a TKA-file.

- Print out a spectrum
  For printing the spectrum click on *Datei* → *Datenplot*. Indicate the channel numbers you want to print if you do not want to print the whole spectrum. The program will not print the zoomed area! You can also choose the labeling of the x-axis or a log scale.

- Info window
  Below the main window there is the Info window which gives you special information about the taken spektrum. You can choose between "Zeit-Info", "Proben-Info", "Nuklid-Info" and "Marker-Info" whereas only the "Zeit-Info" and the "Marker-Info" should be interesting for you.
  "Marker-Info"
  The two markers make it easy to analyze photopeaks in your spectrum. If you put them to the left and the right side of the peak, the program fits a gaussian curve to it and gives you the FWHM (Full Width Half Maximum), the location of the maximum and the integral. You can use this to determine the channel number of the peak while doing your calibration. Be carefull, the progam allways gives you two informations, the first in channell numbers and the second in energy units, the

last is determined by the preset calibration. If you have not set your calibration yet use the channell number information.

3.2.3 Discriminator

A discriminator produces a logical output pulse when the pulse height of an input signal is above a certain threshold. If the pulse height of the signal is to low no response is made, so low amplitude noise can be blocked out. The value of the threshold can be adjusted by a screw on the front panel. We use a leading edge discriminator A disadvantage of this method is the so called "walk" which is illustrated in Figure 11, it means that output signals are dependent on the amplitude of the input pulses, but this is not significant if amplitudes are restricted to a small range.

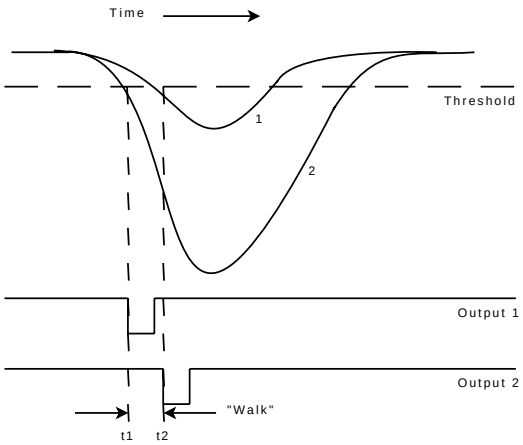


Figure 11: Leading edge discriminator

3.2.4 Time to Amplitude Converter (TAC)

This module converts the time difference between the arrival time of a logical START and STOP pulse to an analog pulse with amplitude proportional to the time difference.

3.2.5 gnuplot

- Make a plot
  Open "gnuplot" click on "ChDir" and insert your working directory.

Gnuplot can only handle with files which are inside this directory. Before you can make a plot you have to insert your datapoints to a chart, this could be a Excel chart or a simple txt-file. Save it in your folder. Now type in:
gnuplot>plot "datei.txt"
gnuplot will plot the second column against the first. If you want to plot for example the second against the third type in:
gnuplot> plot "datei.txt" using 2:3

- linear fit
  gnuplot> $f(x) = ax + b$
  gnuplot> fit $[\underline{x} : \overline{x}][\underline{y} : \overline{y}]f(x)$"*datei.txt*" using columnx:columny via a,b
  gnuplot> plot f(x), "datei.txt" using columnx:columny

- Save as ps-file
  to save a plot as ps-file (so you can convert it to a pdf and print it out) type in:
  gnuplot> set output "datei.ps"
  gnuplot> set terminal post enhanced color solid "Helvetica"
  gnuplot> unset output
  gnuplot> set terminal windows

- Save as gif-file
  gnuplot> set terminal gif
  gnuplot> set output "datei.gif"
  gnuplot> replot
  gnuplot> unset output
  gnuplot> set terminal windows

- Example: "Making a Kuriepot"
  #Energiekalibration
  k=Kalibrierungsfaktor
  m=offset
  #Konstanten:
  #Ruheenergie
  E=511
  #Kernladungszahl
  Z=38

```
#Feinstrukturkonstante
a=1/137
#Fermifunktion/ Coulombkorrektur
F(x)=(pi*(Z*a*(x+E)/(sqrt((x**2)+2*E*x)))/(1-exp(-2*pi*(Z*a*(x+E)
/(sqrt((x**2)+2*E*x))))))
#Kurieplot
plot "datei.tka" using ($0*k+m):(sqrt($1/(F($0)*($0+E)*sqrt
($0**2+2*$0*E))))
#linearer Fit
g(x)= a*x+b
fit [800:1400] g(x) "datei.tka" using ($0*k+m):(sqrt($1/(F($0)*($0+E)
sqrt($0**2+2*$0*E)))) via a,b
#Plot
plot "datei.tka" using ($0*k+m):(sqrt($1/(F($0)*($0+E)
sqrt($0**2+2*$0*E)))) title "Kurie-Plot" with points 4, g(x) title "Fit"
```

3.3 Exposure dose in the experiment

The activity of a source is the number of decays which can occure in a given time. It is usually measured in the unit Curie which are defined as:

$$1 Curie = 3.7 \cdot 10^{10} decays/s = 3.7 \cdot 10^{10} Bq$$

Curie is a very large unit, it was originally defined as the activity of one gram of Radium. One usually deals with sources which have activities in the order of microCurie (μCi).
The radiation dose from ionising radiation absorbed from the body which comprises the effectivity of the radiation to the body is called equivalent dose. Its unit is Sievert (Sv). The sources we use in this experiment have low activity. For comparison, the natural exposure dose which is comprised of the cosmological radiation, terristric radiation and intern radiation averages 2.1 mSv/a. However small amounts of radioactive sources in the body can be very harmful. The sources we use in this experiment are sealed and hence ingestion is impossible assuming their proper handling. Nevertheless one should always obey the following two rules when handling radioactive sources:

1. Never eat, drink or smoke in the laboratory!
2. Wash your hands after handling radioactive sources or lead!

4 Instructions

4.1 A closer look at the scintillators

4.1.1 Assembling a scintillator

Before we start the measurements we will have a look at the individuel components of our detector: the scintillator (in this case an organic scintillator), the lightguide and the photomultiplier. You are supposed to assemble the detector on your own. The single steps of wrapping are shown in figure 12
At first all three pieces (scintillator, lightguide and photomultiplier) have to be wrapped by the white teflon tissue tape. Each winding should overlap in area with the old one by about 1/3. Be careful, do not touch the scintillator or the lightguide with bare hands! Fat finger prints will lead to cracks in the surface of the scintillator and will destroy the total reflection of light.
For the next step you have to wrap all the three pieces with the black scotch tape. You have to do this twice, to make the counter light tight. The second layer is wound with the same winding angle as the first, but shifted by half tape width.

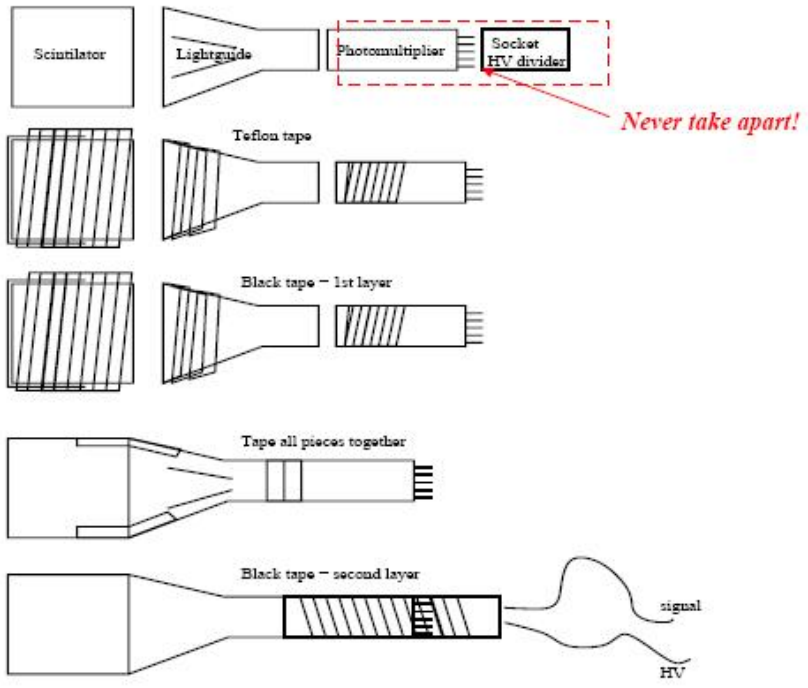


Figure 12: Assemble a organic scintillator

Now you can connect the three pieces together with the black scotch tape. Take care that there are no air gaps between the scintillator and the lightguide and none between the lightguide and the the photomultiplier either. A gap would lead to light losses. All pieces need to have a good mechanical contact at all surfaces to each other. At the end your detector should be mechanically stable and absolutely light tight so you can start your measurements.

4.1.2 Signals of the scintillators

Now we will have a look at the signals of the different scintillators. Use the organic scintillators you have just assembled and the inorganic NaI- scintillators and choose the ^{6}0Co-source. Connect the output of the photomultipliers to the scope and terminate the input channel of the scope by a 50Ω resistor. Make a sketch of the pulses, with time and pulse height informations, into your logbooks.
Put the ^{60}Co source in front of the Scintillators. Can you see any differences between the signal with and without a source? Use the amplifier in the crate and have a look at the amplified signal on the scope.
Compare the signals of the organic and the inorganic scintillators and note down your achievements into your logbooks.
Make a sketch showing the characteristic shape of the signal.

4.1.3 Pulse height vs. high voltage

Connect the output of the photomultiplier of the inorganic scintillator (NaI) via the amplifier to the scope, terminate the input channel of the scope by a 50Ω resistor. Measure the average pulse height of the signal as a function of the HV in steps of 20V up to the given maximal voltage on your scintillator, by means of the oscilloscope. Start at the maximal voltage and make measurements as long as it is reasonable. Make a graph of the results into your logbook, by hand.
How can you interpret your result?

4.1.4 Comparison of the spectra

Arrange your setup like it is shown in figure 13 and use the ^{137}Cs source. Open "Gammamessung- und analyse" on your PC and make yourself familiar with the program, the most important features of this program are given in section 3.2.2. Open the detector and and take a spectrum of the ^{137}Cs for 300 s with the organic and the inorganic scintillator. Describe the spectra and compare them to each other. Why are they so different?

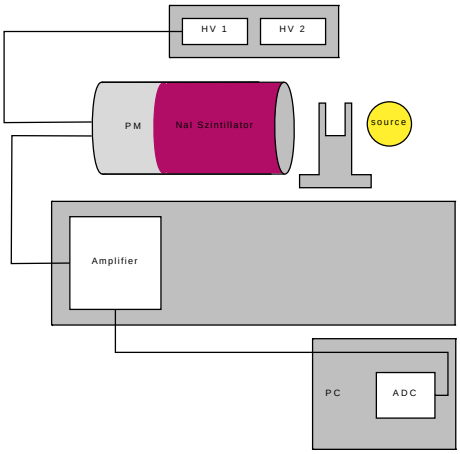


Figure 13: Setup for the energy measurements

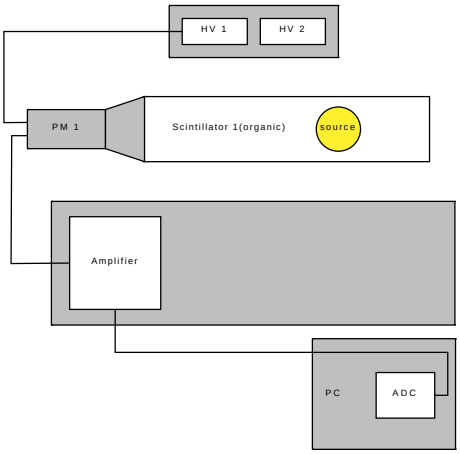


Figure 14: Setup with the organic scintillator

4.2 β Spectrum of the Sr 90 source

The intent of the second part of the experiment is to understand the inorganic scintillators and to use them for a measurement. At the end of this part you will have to determine the endpoint energy of a ^{90}Sr source.

4.2.1 Choosing a working voltage

For choosing a reasonable working voltage we will determine the energy resolution of the detector in dependency of the high voltage. The setup is given in figure 13.
Take the ^{1}37Cs-source and make measurements of it's spectrum in steps of about 30 V, up to the given maximal voltage on your scintillator. Choose a working voltage from your results and keep it for the rest of the measurement.

4.2.2 Calibration

Before we start the measurement of the β spectrum we have to calibrate the detector. As reference sources we use a ^{60}Co and a ^{137}Cs source, their decay schemes are given in part 3.1
Put the ^{60}Co source in front of the scintillator and start the measurement. Adjust the amplifier so that the second peak of the ^{60}Co is approximately in the middle of the spectrum, do not change the amplifying factor again. Save your spectrum and take a spectrum of the ^{137}Cs. Now you have to determine the channel numbers of the photopeaks and calibrate the spectrum.
Insert your three calibration points to the data taking programm by choosing

Kalibrierung → *Nur Energie....* Click on *Kalibrierung* → *Energie-zeigen*, have a look at the energy calibration fit and print it out.
Note down the calibration factor into your logbooks!

4.2.3 Determination of the end-point energy via Kurie-plot

Take a spectrum of the ^{90}Sr source. Compare your spectrum with the theoretical spectrum shown in section 2.1.2 Where does the peak in the low energy levels come from?

Correcting the background For correcting the spectrum you are now supposed to take a background spectrum. Put the plexiglass panel between the source and the scintillator and start the measurement again.
Why is the background spectrum taken with a plexiglass panel?
Save both spectra in your folder. Now you can substract the background from your spectrum by choosing *Optionen* → *abziehen*.
Now you're ready to make your first Kurie-Plot. Save your corrected spectrum as a TKA-file. Copy the data file *Kurieplot* from the desktop in your folder and fit it to your data. Open *gnuplot* and load your kurieplot file by entering: *load "Kurieplot.txt"*. The program will do all the rest, your Kurieplot is saved as a ps-file in your folder. From the fit-file you can determine the endpoint of your spectrum.
Why differs the measured value so much from the literature value? To answer that question consult the sketch of the scintillator given in figure 19 in the appendix. How can you correct for this using the given additives? Determine the corrected endpoint energy.

4.3 Time measurements/ Coincidence measurements

Because of good time resolution, we use the organic scintillators for the time measurements. To increase the rate of cosmic muons use the long inorganic scintillators for the measurements.

4.3.1 Adjusting the threshold of the discriminator

To derive a digital pulse whose leading edge gives us the moment of the arrival of the scintillator pulse we use a discriminator. In the leading edge discriminator a time pulse is generated when the input pulse exceeds an adjustable threshold. Before we start the calibration and the measurements we have to adjust the threshold of the discriminator. It should be adjusted as low as possible to maximize the detection effect of the scintillator, but there should be as little as possible noise too.
For this adjustment you have to look at the input and the output of the discriminator signals on the oscilloscope. Connect the output of the PM to channel 1 of the scope and channel 1 to the input of the discriminator, the output signal should be displayed on channel 2, do not forget to terminate channel 2 of the scope by an 50 Ω resistor. The setup is shown in figure 15. Trigger on channel 2, change the threshold and have a look at the signals. Choose a reasonable threshold for both scintillators!

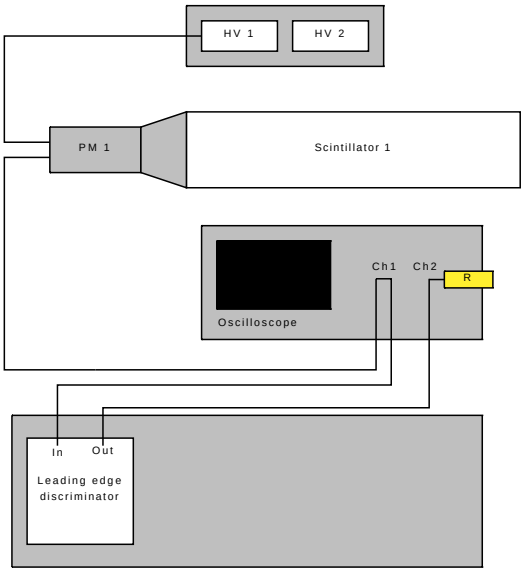


Figure 15: Adjusting the threshold

4.3.2 Adjusting the setup

To measure the time difference between two pulses we use a Time to Amplitude Converter (TAC). One signal is used to start, the other signal is used to stop the measurements. To ensure the stop signal reaches the TAC after the start signal we delay the stop signal using the delay boxes in the crate. Now you can adjust the setup as it is shown in figure 16

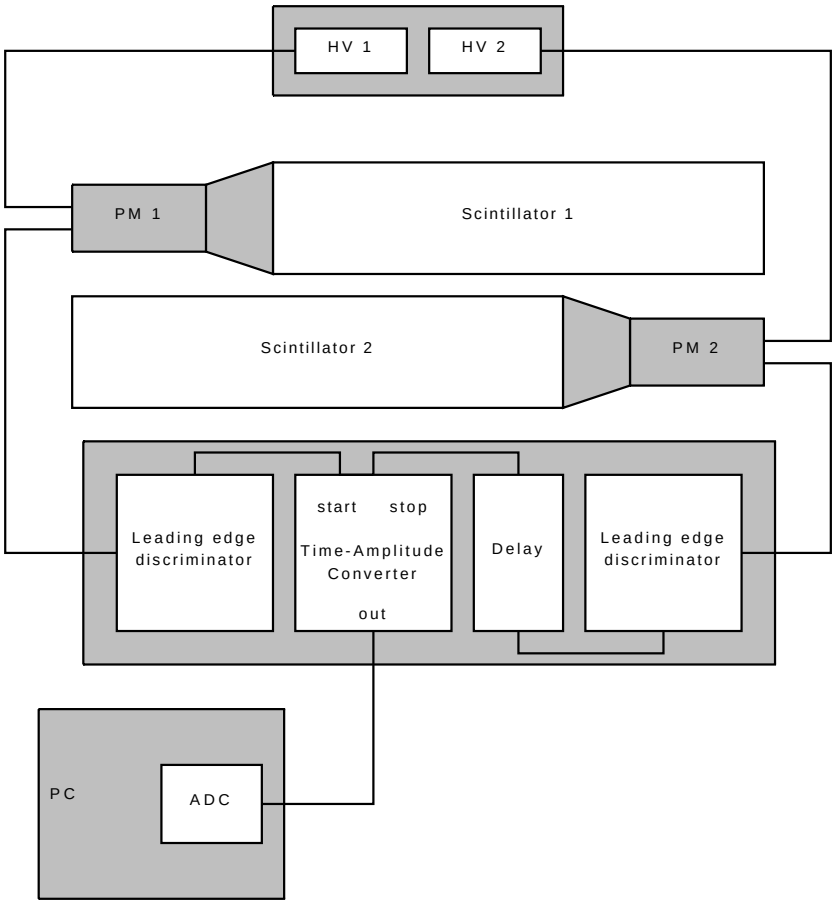


Figure 16: Setup for the time measurements

4.3.3 Working voltage of the organic scintillator

Put the two scintillators on top of each other and connect the photomultipliers to the high voltage unit. The lower scintillator is run with a fixed

voltage of -1500V. Change the voltage of the upper scintillator in steps of 100 V (make more measurements if it is reasonable) from -800V up to -2000 V and take a spectrum. Use the marker options to determine the number of counts in the peak. With the counters in the crate you can measure the counting rates of both scintillators for each voltage.
Now you have to make a background measurement. Position the scintillators so that as few as possible particles can pass both scintillators.
Calculate the accidental coincidences with the formula given in section 2.4.1 and compare them to the measured background.
Plot the counting rate of the counts in the peak against the highvoltage.
Describe your plot, how would you choose your working voltage?

4.3.4 Calibration of the time

To calibrate the time you have to add or take off known delays to the stop pulse in the delay boxes. To shorten the measurements we take only the singnal of one scintillator and delay it to it's original signal like it is shown in figure 17.

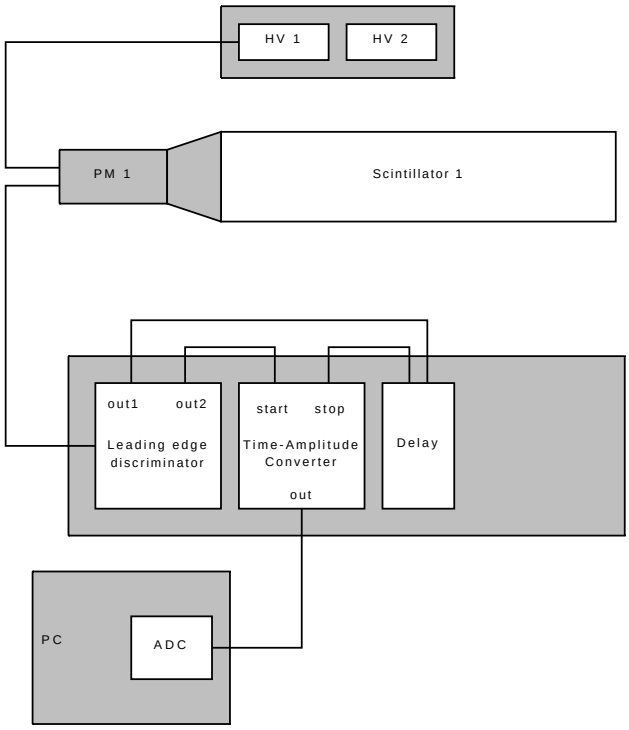


Figure 17: Setup for the time calibration

Start a measurement for about 60 seconds and then add/take off a delay of 4ns. You will see a new peak coming up at a different channel number, the difference in the peak position corresponds to a time of 4ns. Repeat this step for other delays and determine the channel numbers of all your peaks. Plot the delay in ns vs. the channel number and evaluate the calibration factor. (You are supposed to use gnuplot. Using it will make it easier to fit.)

4.3.5 Time resolution

Put one scintillator on top of the other one and take a new spectrum of about 600s with the setup given in figure 16. If you have too much noise, you have to adjust your threshold again!
Determine the time resolution by measuring the Full Width Half Maximum (FWHM). Use the Marker options of the data taking program! Repeat this measurements for antiparallel arranged scintillators and compare the time resolutions of the measurements to each other.

4.3.6 Cosmic muons

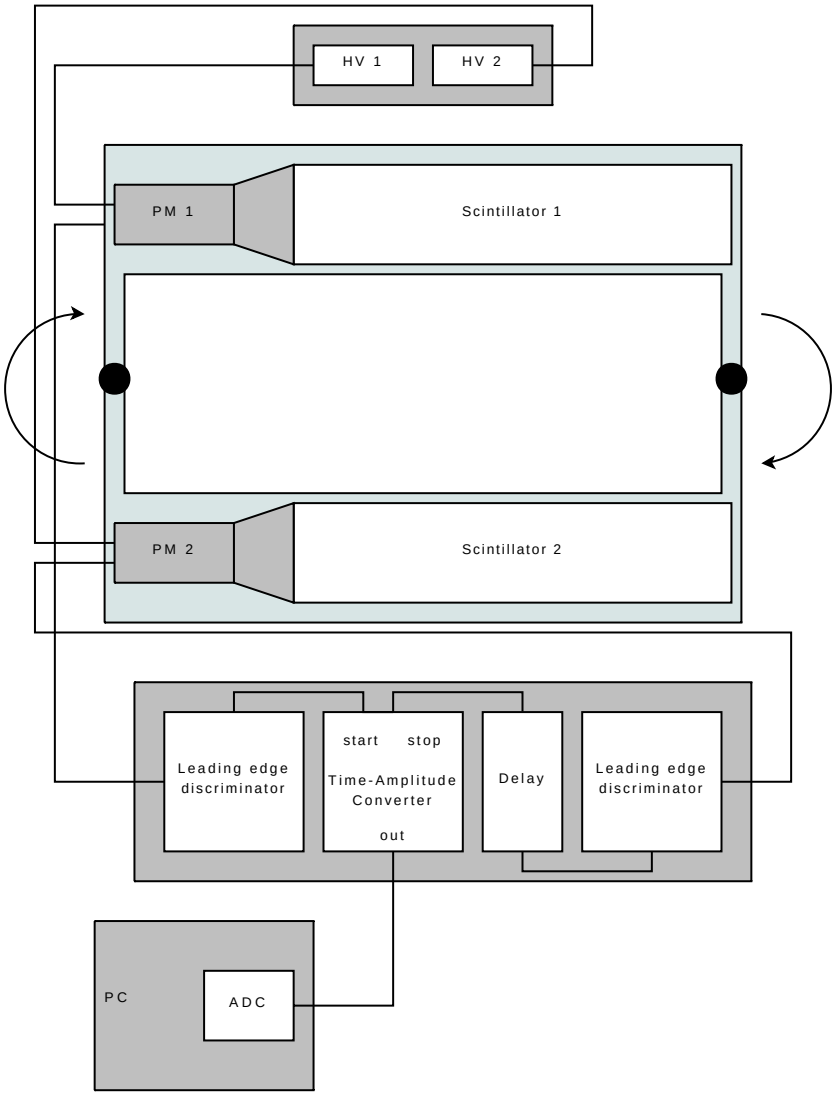


Figure 18: Setup for the measurement of cosmic muons

Put the scintillators into the pivotable setup. Make measurements for every angle $(0°, 22°, 45°, 67°, 90°)$ for 1800s. Make a plot of the counts against the angle of incidence and interpret your plot. (You are asked to start your evaluation during this measurement!)

A Appendix

A.1 NaI scintillator

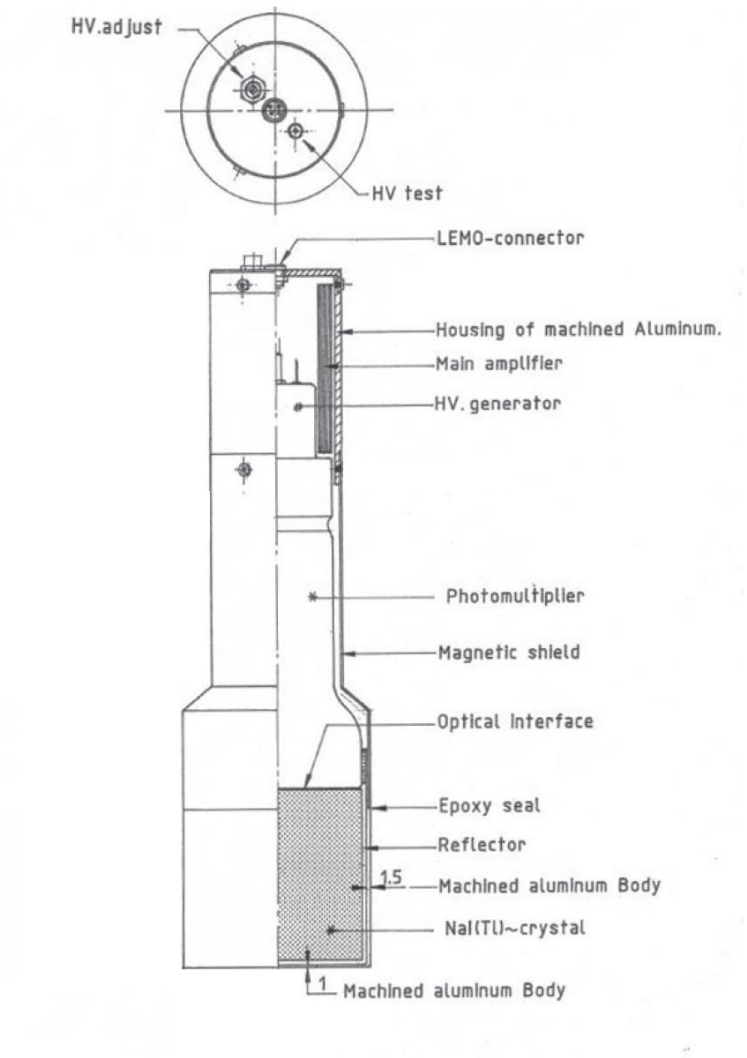


Figure 19: NaI scintillator