Characterisation of plastic scintillators read by SiPMs

LIP, Laboratório de Instrumentação e Física Experimental de Partículas

LIP

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Introduction

This project was completed over the course of the internship.

Our team consisted of four people, unfortunately, only Tiago and Maria were able to attend the presentation.

The objective of this project was the characterization of plastic scintillators read by SiPMs.

What are SiPMs?

A Silicon Photomultiplier (SiPM) is a semiconductor-based sensor designed to detect and measure extremely low levels of light, down to the single-photon scale. It serves as a solid-state alternative to traditional Photomultiplier Tubes (PMTs), offering similar sensitivity while providing advantages such as compact size, enhanced durability, and lower operating voltages.

SiPM application in Muon Detection

In this study, SiPMs are tested at LIP by coupling them with plastic scintillators to detect cosmic muons. The goal is to evaluate their performance specifically signal amplitude, timing resolution, and detection efficienct to compare their effectiveness in detecting minimum ionizing particles (MIPs).

Experimental setup

This setup provided the necessary tools
to obtain accurate and reliable results.

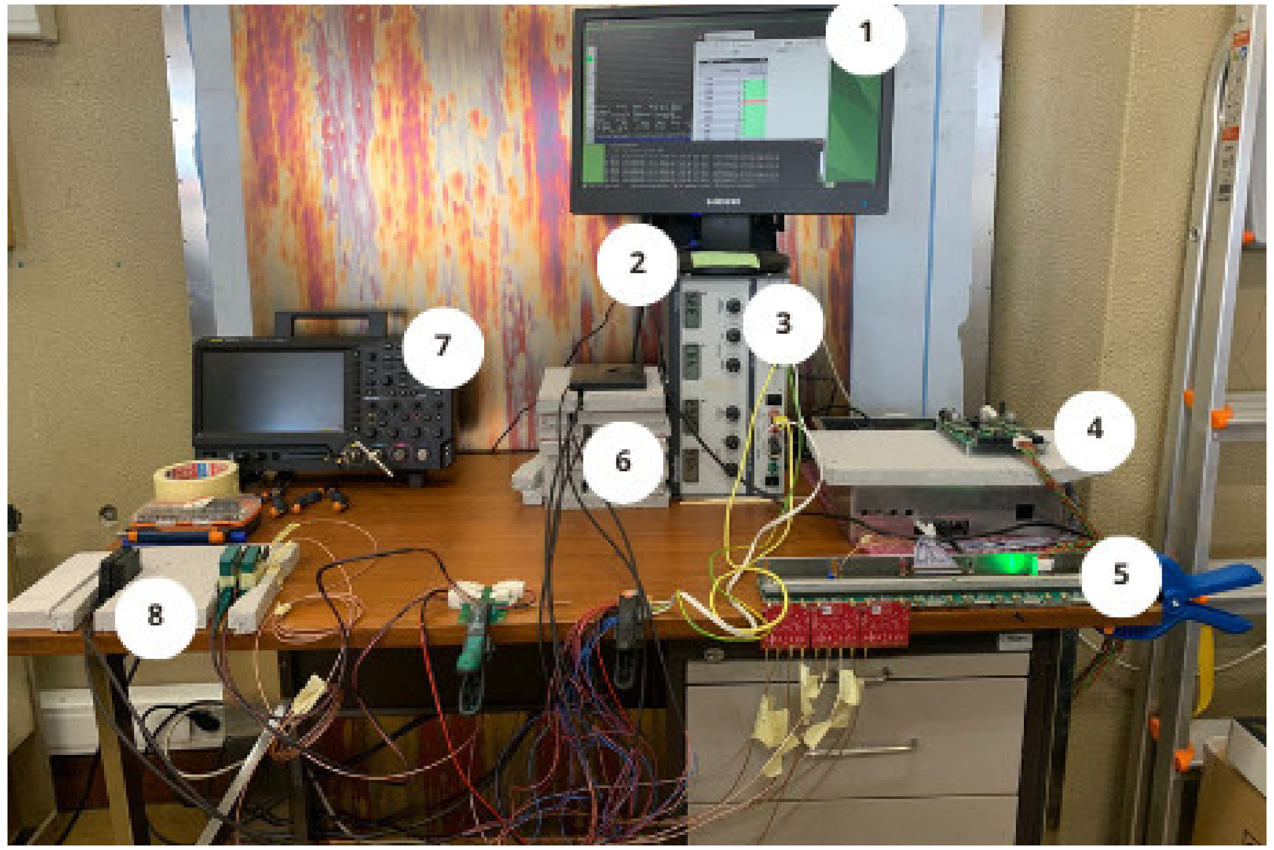

Figure 1. Overview of the full setup: 1. Computer monitor. 2. Router; 3.Power supply. 4. DAQ system; 5. Front End Eletronics; 6. SiPM stack; 7. Oscilloscope; 8. ---

DAQ setup

The DAQ system is shown in more detail in Figure 2, with the different components labeled.

Private Network

To ensure uninterrupted data collection, a private network was set up using an ASUS RT-AX1800 router, protecting the acquisition process from internet outages

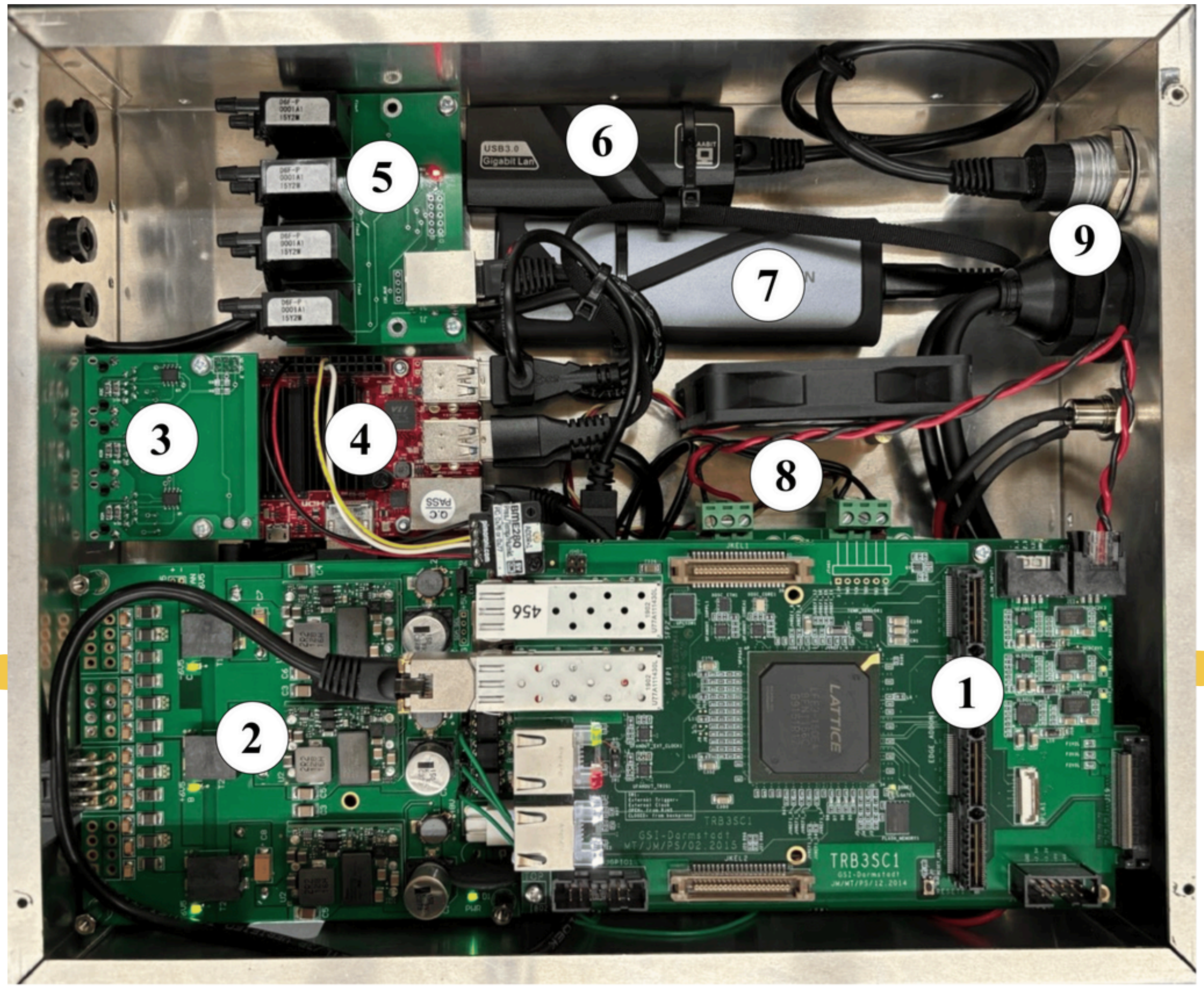

Figure 2. Overview of the Data Acquisition Setup [4]: 1. FPGA Board TRB3SC; 2. LV Power System; 3. I2C distribution board; 4. Mini-PC; 5. Gas Sensor Module; 6. USB Adapter Ethernet; 7. NVMe M.2 SSD; 8. Relay Control Board; 9. Power and computer connections.

SiPM Stack Assembly

Figure 4. Overview of the SiPM Stack

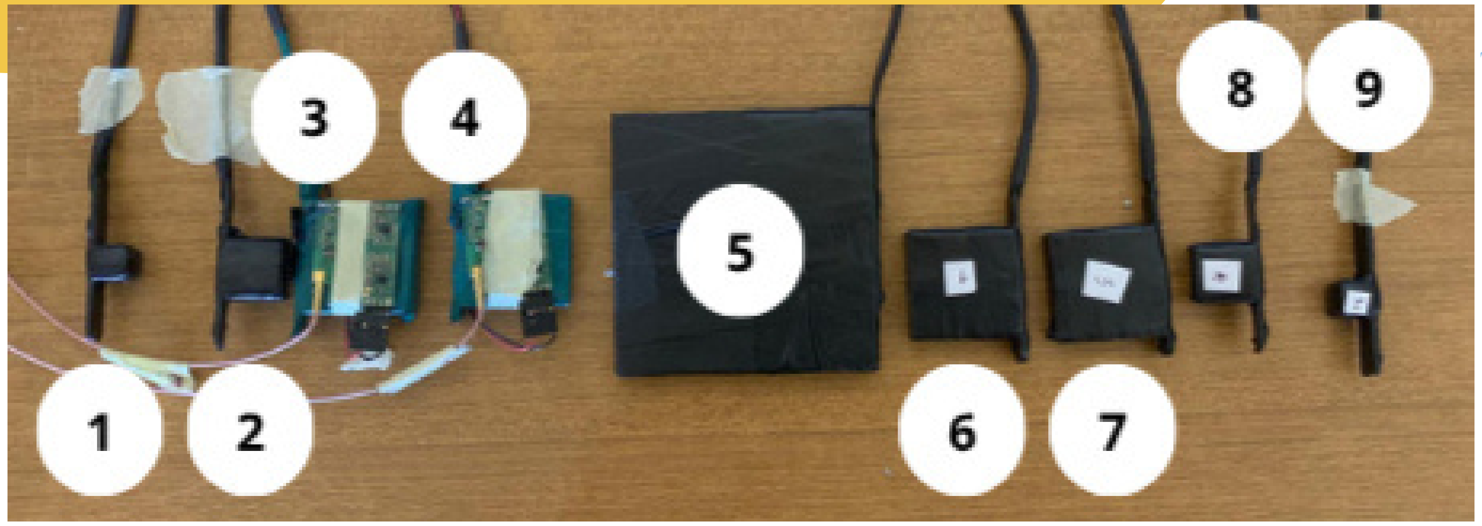

Figure 5. Photograph showing all detectors used in the project,
labeled from left to right: 1. 1×1; 2. 2×2; 3. 4×4; 4. 4×4; 5.10×10; 6. 4×4; 7. 4×4; 8. 2×2; 9. 1×1.

Note:Figure 5 displays all detectors used, each consisting of a plastic scintillator coupled with a SiPM. Detectors 3 and 4 use the same SiPM model but are connected via the fast output. This allows for enhanced timing performance and faster signal processing.

Data Analysis

The resolution was determined by analyzing the timing differences and fitting a Gaussian function to the data. The resulting standard deviation was then used as input to a system of linear equations.

$$\begin{bmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \\ 0 & 1 & 1 \end{bmatrix} \cdot \begin{bmatrix} \sigma_i^2 \\ \sigma_j^2 \\ \sigma_k^2 \end{bmatrix} = \begin{bmatrix} \sigma_{ij}^2 \\ \sigma_{ik}^2 \\ \sigma_{jk}^2 \end{bmatrix}$$

The efficiency was calculated as the ratio of the number of events that coincide in three detectors and the number of events coincident in the other two detectors

$$E_j = \frac{N_{ijk}}{N_{ik}}$$

Results: Experimental Layouts

1st Setup
3 Detector Setup

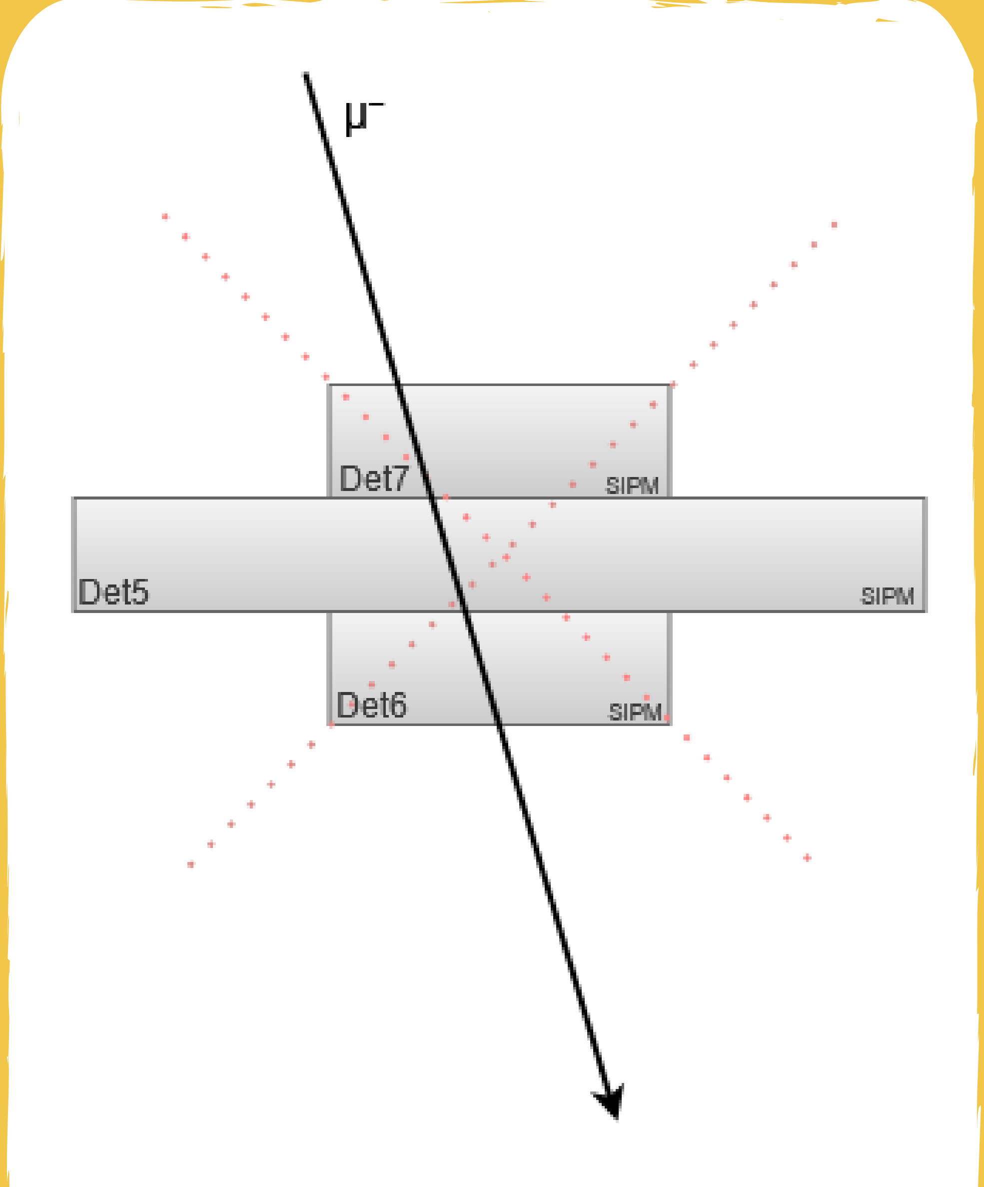

Figure 6. 1st Detection Setup

2nd Setup
9 Detector Setup

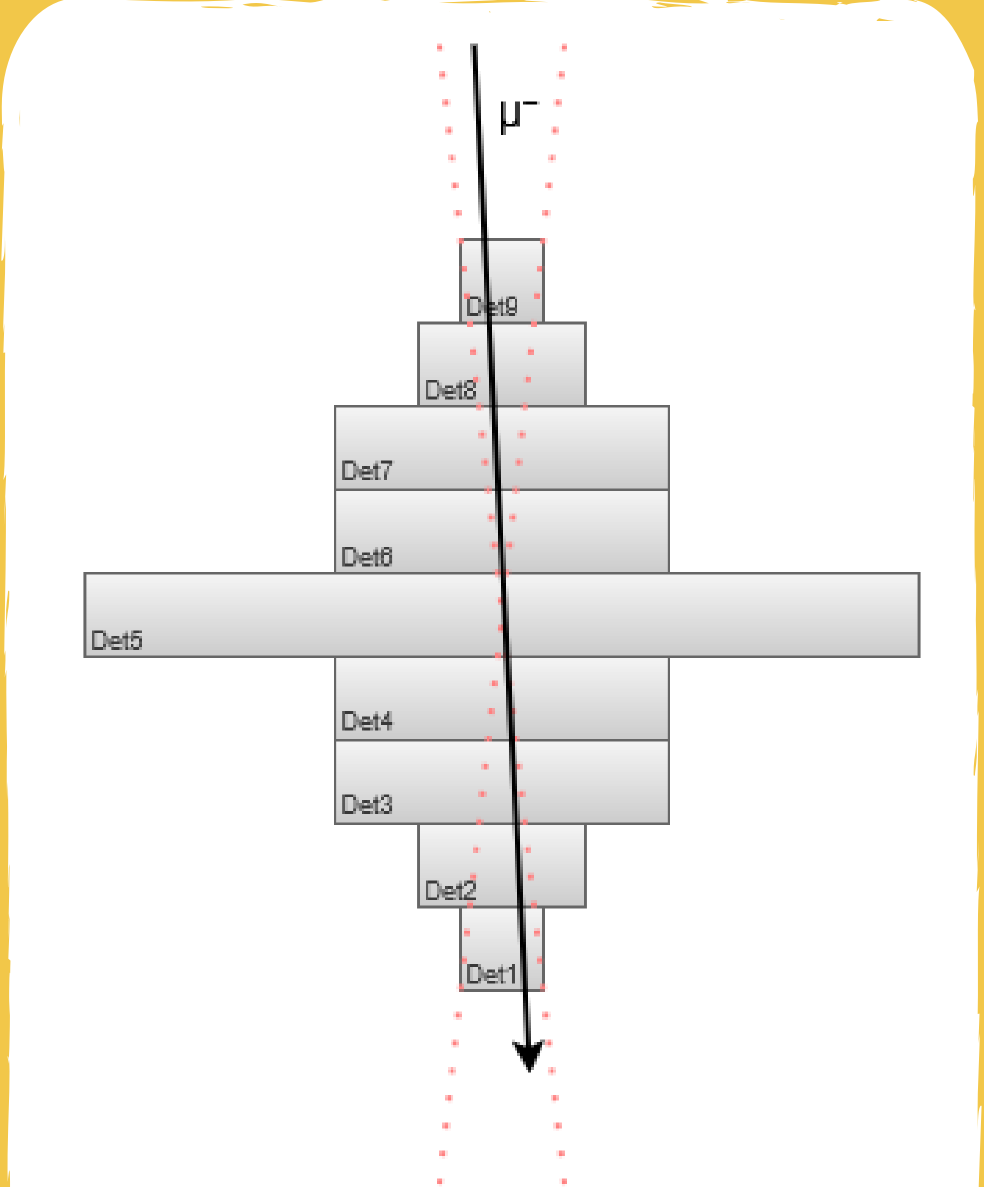

Figure 7. 2nd Detection Setup

Results: Experimental Layouts

3rd Setup

9 Detectors divided into 2 stacks

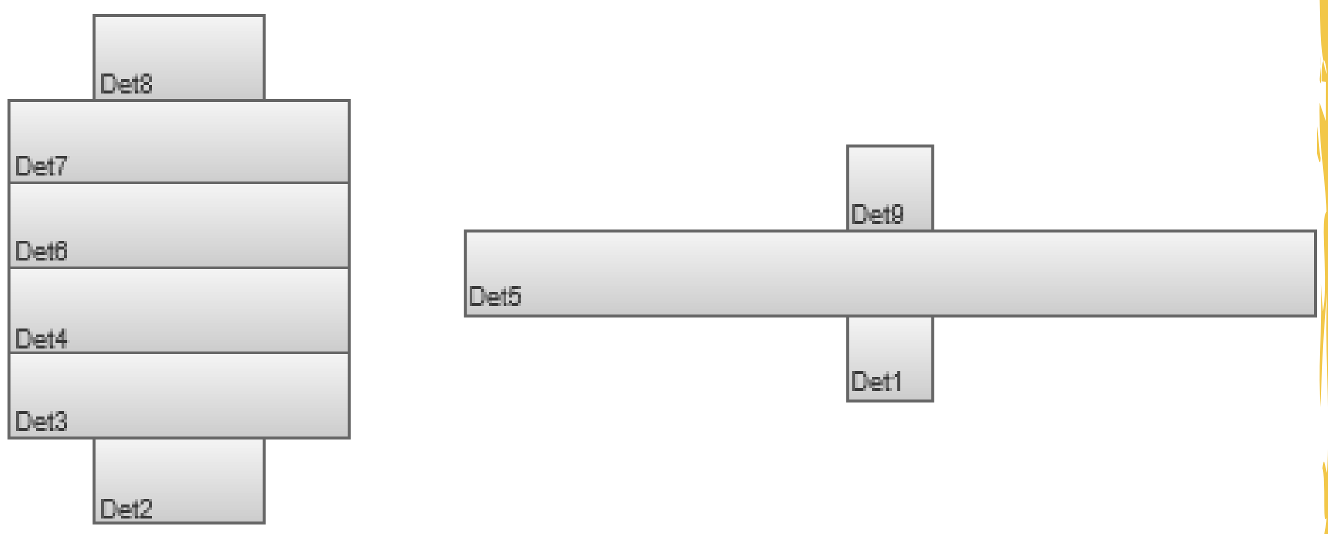

Figure 8. 3rd Detection Setup

4th Setup

4 Detector Setup with a Na-22 source

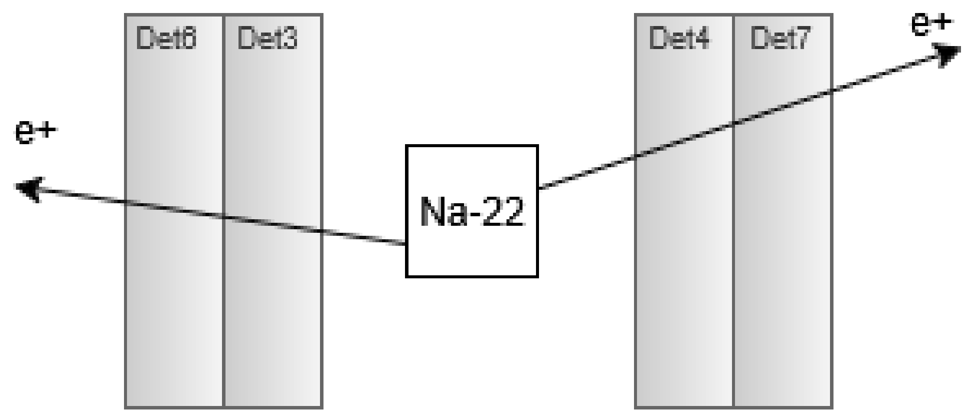

Figure 9. 4th Detection Setup

1st Setup

In this configuration, Detector 5 was placed between Detectors 6 and 7.

A total of nine positions were tested where certain parameters were measured :

- Time resolution
- Average charge amplitude
- Detection efficiency

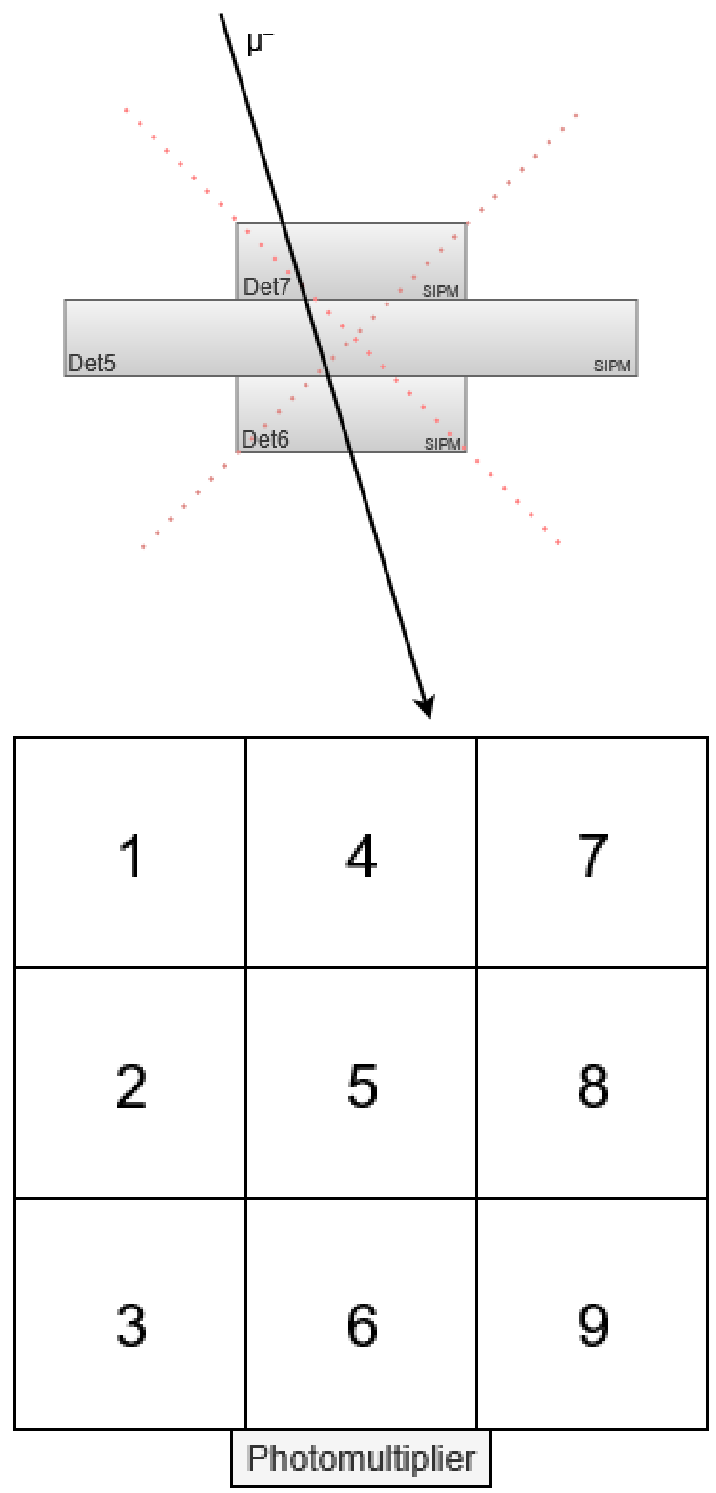

Figure 10. All detector positions of detector 5

1st Setup

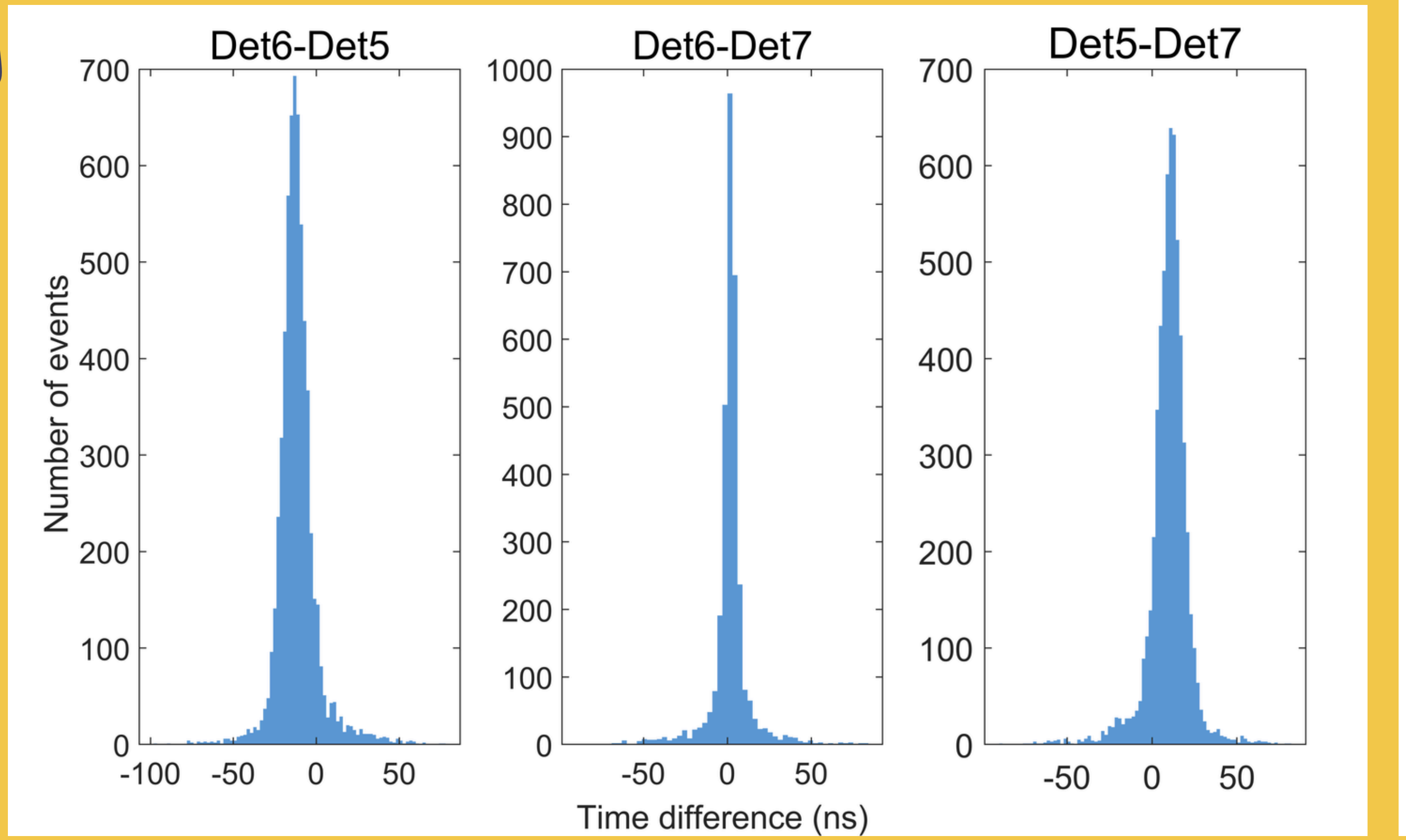

Figure 11. Time difference distribution

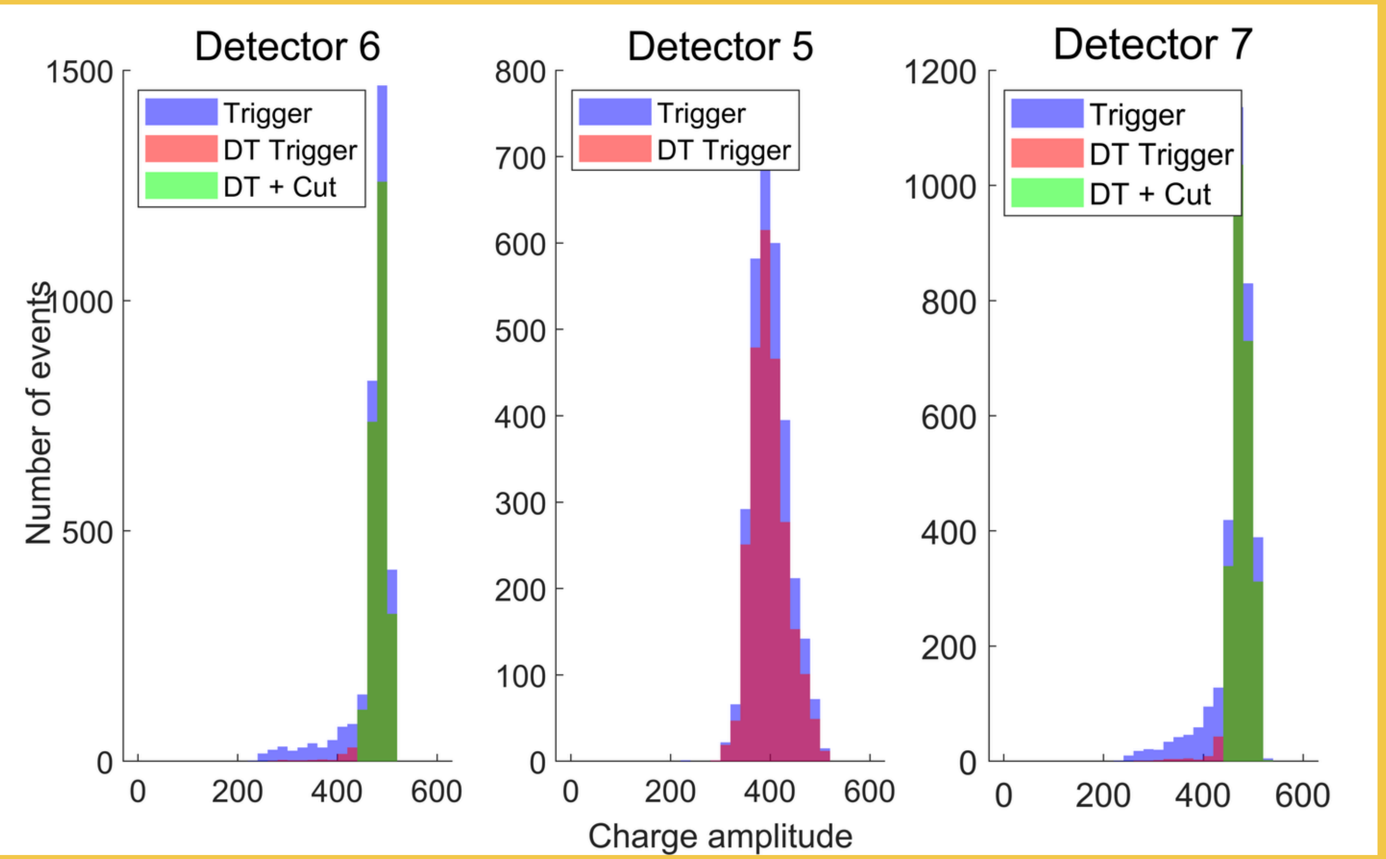

Figure 12. Charge amplitude distribution with triggers applied

1st Setup

	1	2	3	4	5	6	7	8	9
σ_6	2.198	1.644	3.077	2.619	2.967	1.925	2.610	2.348	1.966
σ_5	6.663	6.964	8.600	6.759	6.048	5.612	6.936	7.435	8.149
σ_7	2.588	2.726	2.151	2.834	2.534	2.747	2.926	2.982	3.539
$\sigma_{6,7}$ (corrected)	1.140	0.990	1.057	1.180	0.924	1.000	0.960	1.046	0.891
Average Q6	470.251	470.148	464.526	463.868	466.552	471.775	464.743	463.580	464.892
Average Q5	399.993	400.913	399.651	393.398	406.633	429.215	394.325	392.134	397.105
Average Q7	464.322	464.091	455.113	457.932	459.270	464.390	458.394	454.423	456.795
Efficiency	0.971	0.968	0.975	0.979	0.983	0.977	0.976	0.982	0.978
Efficiency (DT)	0.988	0.995	0.990	0.991	0.994	0.992	0.991	0.994	0.989

Table 1. Overview of detector parameters across all positions

1st Setup

1 σ5 6.663 Average Q5 399.993 Efficiency 0.971 Efficiency (DT) 0.988	4 σ5 6.759 Average Q5 393.398 Efficiency 0.979 Efficiency (DT) 0.991	7 σ5 6.936 Average Q5 394.325 Efficiency 0.976 Efficiency (DT) 0.991
2 σ5 6.964 Average Q5 400.913 Efficiency 0.968 Efficiency (DT) 0.995	5 σ5 6.048 Average Q5 406.633 Efficiency 0.983 Efficiency (DT) 0.994	8 σ5 7.435 Average Q5 392.134 Efficiency 0.982 Efficiency (DT) 0.994
3 σ5 8.600 Average Q5 399.651 Efficiency 0.975 Efficiency (DT) 0.990	6 σ5 5.612 Average Q5 429.215 Efficiency 0.977 Efficiency (DT) 0.992	9 σ5 8.149 Average Q5 397.105 Efficiency 0.978 Efficiency (DT) 0.989

Figure 13. Characteristics of detector 5 across all positions

2nd Setup

All detectors were stacked vertically on top of one another and aligned centrally.

The goal was to evaluate their efficiencies and time resolutions. The efficiencies were obtained using quadruple coincident events.

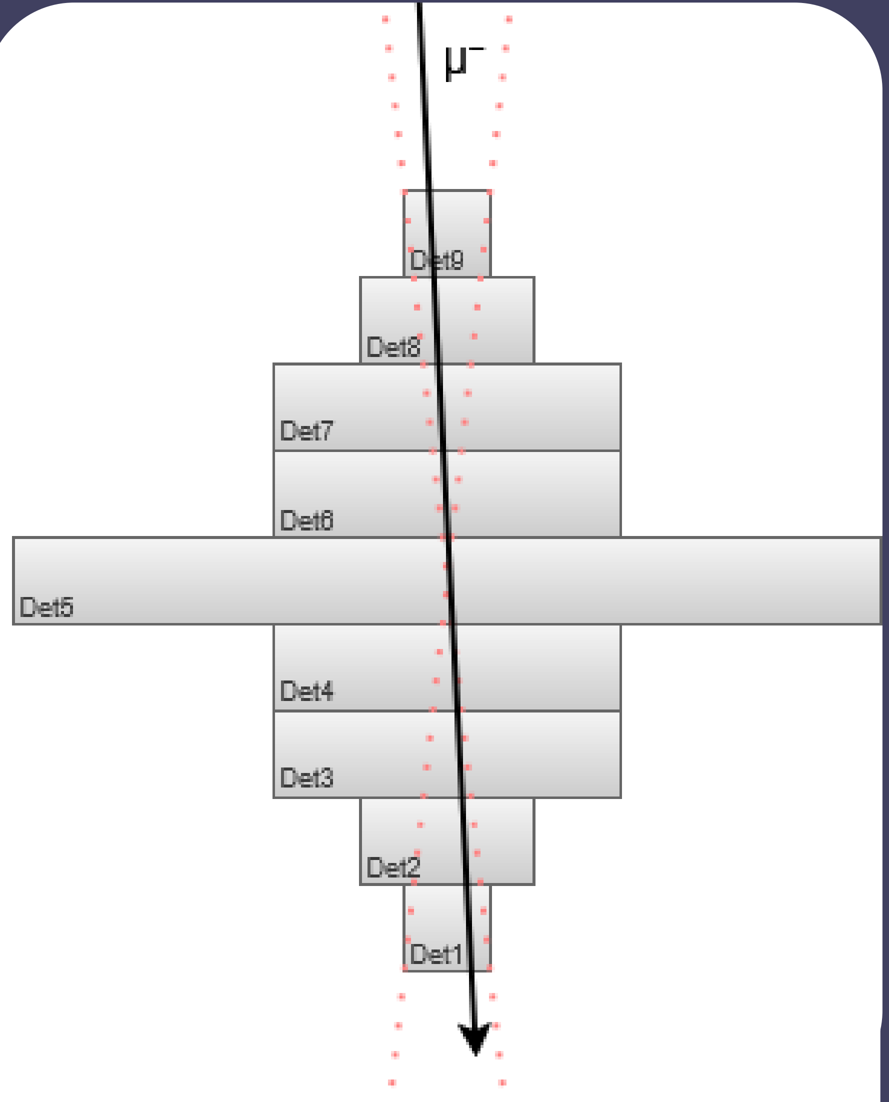

Figure 7. 2nd Detection Setup

2nd Setup

All detectors exhibited similar efficiencies, with values around 0.99

There is a correlation between charge amplitude and scintillator area: as the area increases, the average charge amplitude decreases.

Detector	Efficiency ± Error
2	0.9524 ± 0.0722
3	0.9978 ± 0.0464
4	0.9886 ± 0.0566
5	1.0000 ± 0.0205
6	0.9937 ± 0.0457
7	0.9937 ± 0.0457
8	0.9805 ± 0.1123

Detector	Average Charge Q	Resolution
9	412.7879	2.2427
8	453.7613	1.3797
7	376.9429	2.9266
6	379.1820	1.7787
5	342.4781	7.7091
4	281.1178	0.426
3	299.7581	0.426
2	476.5386	1.0680
1	463.5494	2.0772

Table 2 and 3. Detector parameters

2nd Setup

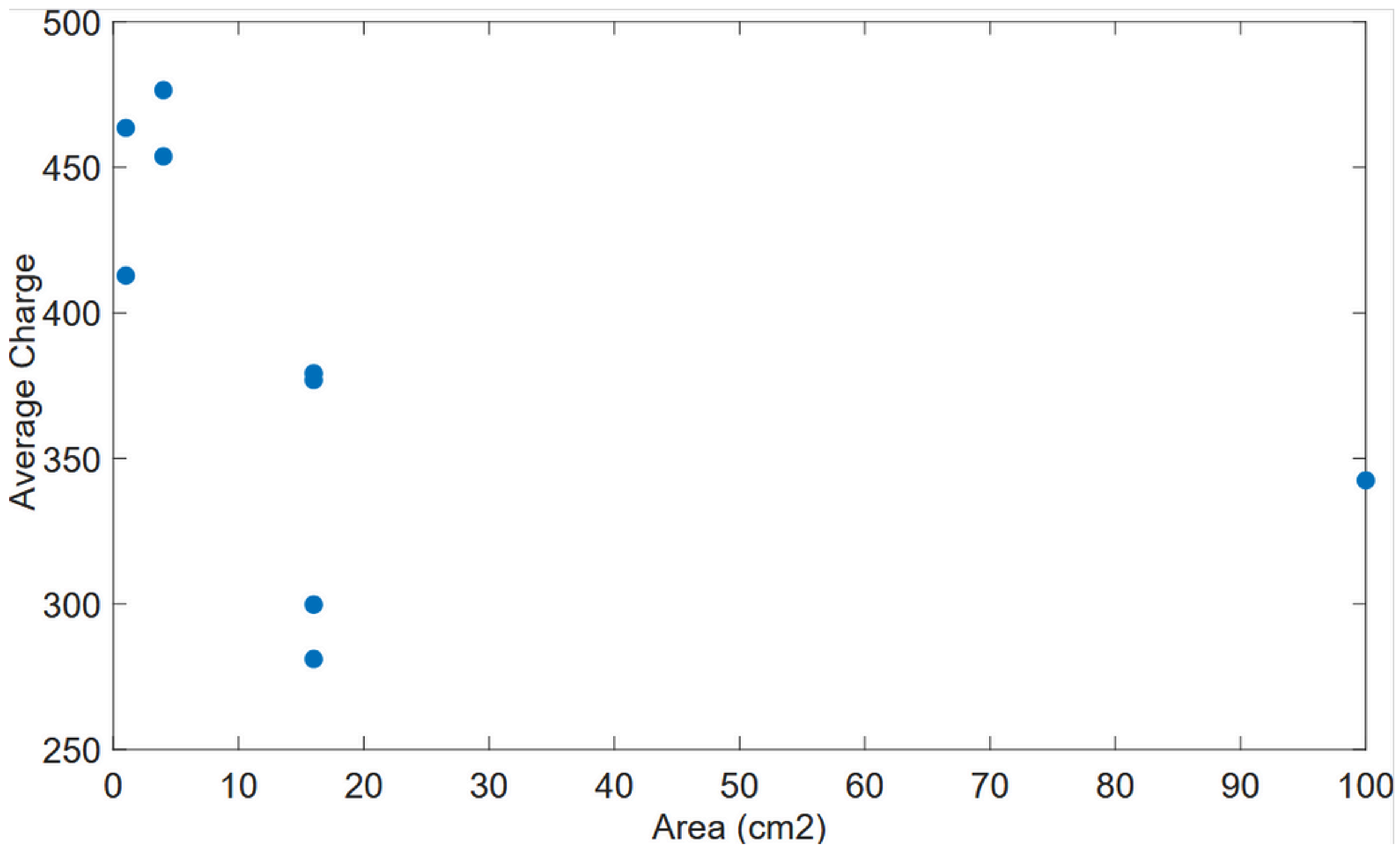

Figure 14. Scintillator area vs Average charge

3rd Setup

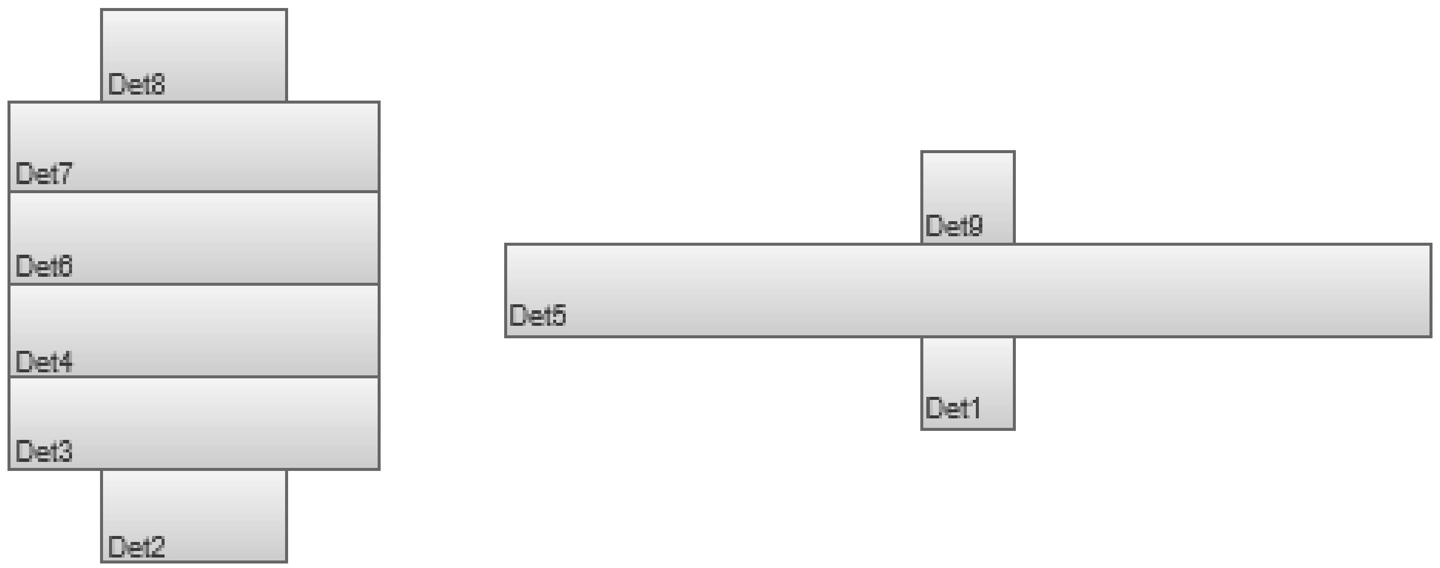

Figure 8. 3rd Detection Setup

The detector stack was divided into two groups:

- Detectors 2, 3, 4, 6, 7, and 8
- Detectors 1, 5, and 9

This configuration was used to measure coincidences between the two stacks, as well as to study the dependence of the detected event rate on the separation distance between them

3rd Setup

Detector	Efficiency ± Error
7	0.994 ± 0.079
6	0.991 ± 0.078
4	0.988 ± 0.078
3	0.988 ± 0.078

Detector	Average Charge Q	Resolution
9	412.264	—
8	458.055	1.349
7	376.339	3.374
6	377.125	2.411
5	343.783	—
4	277.744	0.388
3	294.048	0.388
2	470.633	1.292
1	460.291	—

Table 4 and 5. Detector parameters

4th Setup

Detectors 3, 4, 6, and 7 were paired and positioned vertically at a distance, with a Na-22 source placed between the pairs .

Detectors 3 and 4 have a faster output. This layout was used to obtain their time resolution. As such, their timing differences and charge amplitude were measured

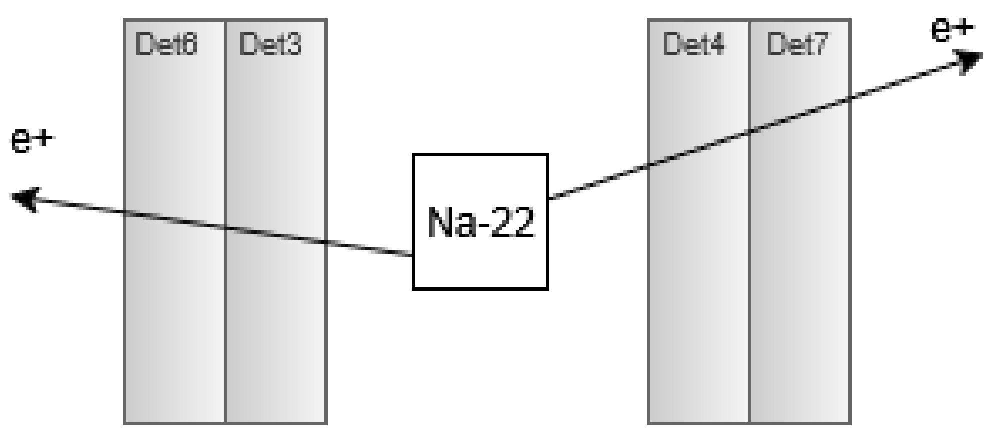

Figure 9. 4th Detection Setup

Detector	Resolution
3,4	1.542
6,7	15.343

Table 6. Detector resolution

Conclusions