Cosmic Ray Muon Detection

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Abstract:
The aims of this project were:

→ To assemble a cosmic ray muon detector using scintillation materials and Photomultipliers (PMT)

→ To measure cosmic ray muons

→ To study angular distribution of muons and influence of building thickness on this distribution

Muons:
Muons are elementary subatomic particles similar to the electron but 207 times heavier. They are produced in the upper atmosphere by the decay of pions produced by primary cosmic rays:

\[
\pi^+ \rightarrow \mu^+ + \nu_\mu \quad \pi^- \rightarrow \mu^- + \bar{\nu}_\mu
\]

It has two forms, the negatively charged muon and its positively charged antiparticle. The muon was discovered as a constituent of cosmic-ray particle “showers” in 1936 by the American physicists Carl D. Anderson and Seth Neddermeyer. Because of its mass, it was at first thought to be the particle predicted by the Japanese physicist Yukawa Hideki in 1935 to explain the strong force that binds protons and neutrons together in atomic nuclei. It was subsequently discovered, however, that a muon is correctly assigned as a member of the lepton group of subatomic particles i.e., it never reacts with nuclei or other particles through the strong interaction. A muon is relatively unstable, with a lifetime of only 2.2 microseconds before it decays by the weak force into an electron and two kinds of neutrinos. Because muons are charged, before decaying they lose energy by displacing electrons from atoms (ionization). At high-particle velocities close to the speed of light, ionization dissipates energy in relatively small amounts, so muons in cosmic radiation are extremely penetrating and can travel thousands of metres below the Earth’s surface.

Scintillation Detectors:
The scintillation detector is undoubtedly one of the most often and widely used particle detection devices in nuclear and particle physics today. It makes use of the fact that certain materials when struck by nuclear particle or radiation, emit small flashes of light, i.e. scintillation. When coupled to an amplifying device such as a photomultiplier, these scintillations can be converted into electrical pulses which can then be analyzed and counted electronically to give information concerning the incident radiation.
Research:

Two small plastic scintillators connected with PMT’s and the big one which was connected with two PMT’s through the lightguides were used in current project. In nuclear and particle physics, plastic scintillators are probably the most widely used of the organic detectors today. Like the organic liquids, plastic scintillators are also solutions of organic scintillators but in solid plastic solvent. Plastics offer an extremely fast signal with decay constant of about 2-3 ns and high light output. One of the major advantages of plastics is their flexibility. They are easily machined by normal means and shaped to desired forms. They are produced commercially in wide variety of sizes and forms, ranging from thin films, to large sheets, blocks and cylinders, and are relatively cheap. Moreover, various types of plastics are made offering differences in light transmission, speed, etc.

During the experiment the big scintillation board was placed between two small scintillators. After displacing them in every 10 centimeters left and right from the center of a large scintillator, pulse height difference and time difference between signals at the output of each PMT’s was measured. On Figure 1 and Figure 2 are shown the results for 50 centimeters displacement from the center. From Figure 3 it’s clear that time difference is more correlated than pulse difference. Therefore in purpose to find the hit position x and its deviation $\sigma_x$ Figure 2 was used: From the time difference $t_i$ and the number of events $n_i$ of the i-th bin of the histogram the average time and time deviation were found:

$$\bar{t} = \frac{\sum n_i t_i}{\sum n_i}$$

$$\sigma_t^2 = \left(\bar{t} - \bar{t}\right)^2$$

After the curve fitting and finding an equation of the straight line in the calibration curve of $\bar{t}$ v.s. x shown in Figure 4, the deviation $\sigma_x = \frac{6.7}{cm}$ was found through $\sigma_t$. It was also found that $x = 0$, the center of the big scintillator, corresponds to $\bar{t} = -1.0$ ns

![Figure 1](image-url)
Figure 2

Figure 3
Figure 4

(Calibration Curve)

Angle Distribution:

Figure 5
On the Figure 5 is shown the plant for measuring cosmic ray muons angular distribution. This plant consists of two scintillation boards, each connected to PMT’s. The overall distribution of muons in zenith angle $\theta$ at the ground is $\propto \cos^2 \theta$. It should be noted that the measured angular distribution does not correspond to the actual angular distribution because acceptance of our detector depends on the angle. The acceptance could be estimated by a Monte Carlo simulation, but it is beyond the scope of the present work. During the experiment the main goal was to establish the influence of thickness of building on angular distribution of muons. On Figure 6 is shown the angular distribution which was obtained with the detector halfway across the joint between building ‘Area W’ and the bridge connecting ‘Area W’ with ‘Area C’ on sixth floor in Science bulg.1 (Figure 7). The vertical line at time difference $+1.0$ ns indicates the direction $\theta = 0$ Originally, it was $-1.0$ ns, but left-right of Figure 6 was reversed in order to fit the direction of Figure 7. It is clear from this chart that some muons which pass a longer path through the building are absorbed by the building. The result is an asymmetric distribution which differs from theoretical distribution.

Figure 6

(the angular distribution (red) with symmetrically reflected right side (green))
On Figure 8 is shown the angular distribution which was obtained with the same detector in the middle of tenth floor in Science bulg.1. The vertical line at time difference $+1.0$ ns also indicates the direction $\theta = 0$. Unlike the distribution obtained on the sixth floor, the current distribution is symmetrically about the vertical line at time difference $+1.0$ ns. This result had been expected because muons have not met any obstacles in their paths.
Discussion and conclusion:

The main goal of this project was to obtain the angular distribution and determine the effect of the thickness of a building on this distribution. To achieve this goal I made measurement to get a calibration curve as described above. Using this calibration curve to process the data which was obtained during the experiment, the effect of the thickness of a building on the angular distribution was determined. On Figure 6 and on Figure 8 you can see the results.