Z37 - Muon Lifetime

Physics Laboratory II – academic year 2017/2018
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The aim of the experiment is to determine the lifetime of muons. These particles are similar to electrons. They differ from electrons by more than 200 larger mass. Muons are unstable. They decay in the weak interaction and knowledge of their lifetime allows to determine the strength of the weak interaction (Fermi coupling constant).
In the experiment, positively charged muons originating from the cosmic rays are stopped in a scintillation detector and subsequently decay with the positron emission. The muon lifetime is determined based on a time difference between the detector signal produced by the stopped muon and the signal generated by the positron emission.

Preparatory questions

1. Basic information on the origin, composition, intensity and energy distribution of cosmic rays [1, 2, 3].
2. Properties of muons including quantum numbers and decay channels [2].
3. Explain the measurement method presented in [4].

Computational assignments

Determine the probability, that muon with momentum $1GeV/c$, produced 10 km above the Earth and moving vertically towards it, will reach its surface, i.e. it will not decay earlier.

One of the possible schemes of calculation is as follows:

1. Calculate the speed of the muon.
2. Determine the elapsed time from the moment of the muon production until the surface of the Earth is reached in the reference frame associated with the Earth surface, and then recalculate that time to the muon reference frame.
3. Calculate the probability that the muon does not decay until it reaches the surface of the Earth using the law of the radioactive decay and assuming that the muon lifetime is approximately $2.197\mu s$.

Apparatus and materials

The experimental setup is shown in figure 1. Its basic element is a scintillation detector consisting of four rectangular plastic scintillator plates with dimensions 50 cm x 9 cm x 0.5 cm, stacked alternately with four lead plates, which, due to high energy losses of the passing muons, increase the probability of stopping the muons in the detector. The scintillator plates are read out at both ends by a pair of photomultipliers. Signals from the detectors are fed to electronics system consisting of a few modules – in particular of a discriminator module, coincidence unit, time-to-amplitude converter and amplitude-to-digital converter. A wiring scheme of the electronics system is given in [4].

Experiment

Proposed measurement procedure is as follows:

1. Set up and check the electronics system for the measurement of the muon lifetime. The scheme of the system and details of its commissioning are given in [4].
2. Perform time calibration of the system.
3. Perform measurements of the muon lifetime. In order to reach satisfactory event statistics of the order of 10^3 , it is advisable to conduct the measurement for the whole week until the next laboratory.

Data analysis

1. Prepare a calibration graph i.e. the relation between the time difference t and the channel number. Fit this relation with a straight line which approximates the calibration.
2. For determination of the muon lifetime plot the dependence of the number of counts as a function of time t.
3. Fit the experimental points in the obtained plot using exponential function of the form $N = a \cdot exp(-t/\tau) + b$. The coefficients a, τ, b are obtained from the fit. The value of b determines the level of accidental coincidences. The coefficient τ is the muon lifetime.
4. In determining the muon lifetime, account for the statistical uncertainty of τ as well as the systematic uncertainty associated with the time calibration of the measuring apparatus.
5. Compare obtained result for the muon lifetime with the value given in the literature.

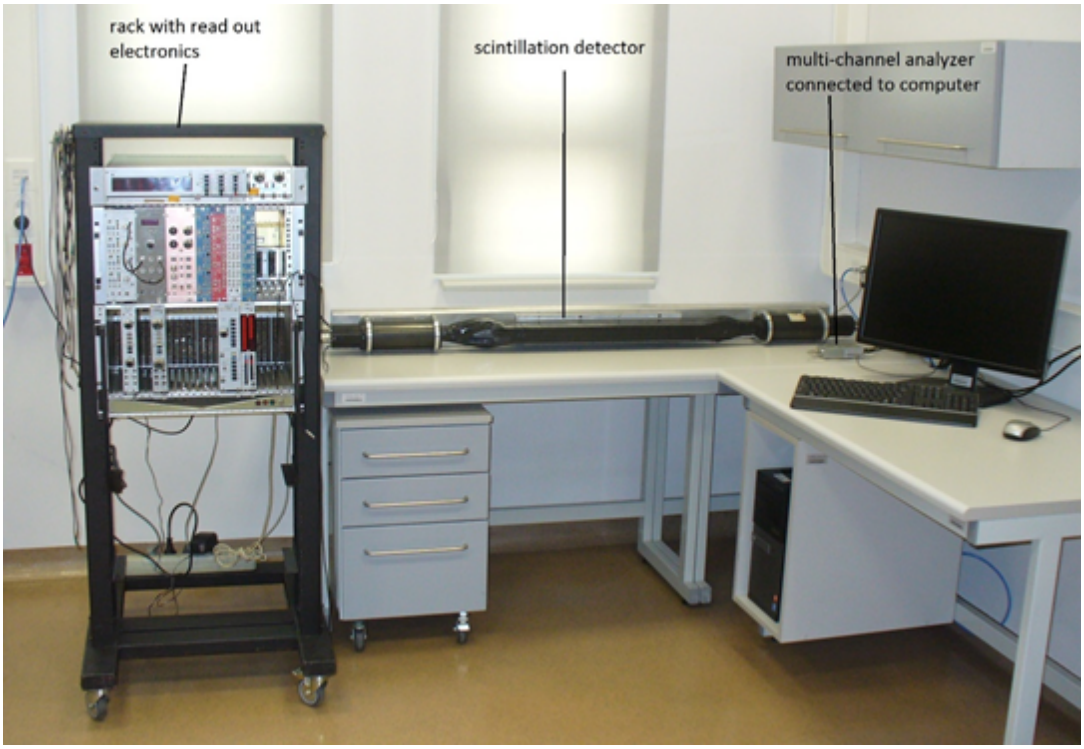

Figure 1: Scintillation detector and read out electronics for measurement of the muon lifetime.

Safety rules

Do not disassemble (e.g. by removing the enclosure) the electronic devices, high voltage supplies and the detectors, as this may cause electric shock.

References

[1] http::/ /en.wikipedia.org/wiki/Cosmic_ray

[2] D. H. Perkins, *Introduction to high Energy physics*

[3] The Review of Particle Physics 2016, chapter 29: Cosmic rays

[4] Instruction for the experiment Z37 - in polish