Čerenkov Effect / Cosmic Radiation

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Abstract

Muons make up a large part of the secondary cosmic radiation which reaches the surface of the earth from the atmosphere. A useful method to observe and quantify them is via the Čerenkov effect. The goal of this experiment is to measure the angular dependence of incoming muons with the help of two detectors in coincidence.

Contents

1 Introduction

1.1 Cosmic radiation

The relationship between astro- and particle physics as the study of the biggest and smallest natural phenomena, respectively, does not seem intuitive at first glance. Yet, there are many topics that both branches of physics have in common. One of them is cosmic radiation which allows high energy physics experiments at low intensities without having to construct a particle accelerator.

Primary radiation that reaches us from space consists of 85% protons, 14% α particles and 1% heavier nuclei. Through interaction with the earth's atmosphere other particles are created which we call secondary radiation. A large part of this radiation consists of high energetic muons which can reach the ground and thus be measured easily. [1]

1.2 Čerenkov effect

If an object moves through a medium faster than the speed of sound, a shock wave spreads behind it in a cone shape. We call this a sonic boom. A similar effect can be observed with electromagnetic waves. In a transparent medium with refraction index n the speed of light c_m is reduced with respect to the vacuum speed of light c:

$$c_m = \frac{c}{n}.$$

As soon as a charged particle moves through a medium at speed $v > c_m$, an electromagnetic wave will spread behind it in a cone shape. [2] Pavel Čerenkov received the Nobel prize in 1958 for the explanation of this phenomenon. [3]

Utilizing the Čerenkov effect, it is possible to determine the direction from which the cosmic muons reach the surface of the earth by taking into account the opening angle of the light measurement device. To improve the angular resolution, an independant detector can be set up in coincidence.

2 Experiment

2.1 Set-up

The following components are provided for the experiment:

- 1 Čerenkov detector
- 1 Scintillator
- 2 Photomultipliers (PMT)
- 1 NIM Crate
- 1 QUAD-Discriminator
- 1 QUAD-Coincidence
- 2 HV sources
- 1 Counting scaler
- 1 Digital oscilloscope with USB port
- Various LEMO cables, 50 Ω resistances and connectors

As a first step, you should make sure that everything you need for the experiment is at hand and familiarize yourselves with how the measurement device works.

2.1.1 Detectors

The Čerenkov detector consists of a polished acrylic glass rod ($\emptyset = 5$ cm, length = 15 cm, n = 1,49) in a light-tight aluminum cylinder. It is optically coupled with a PMT. [4] The second PMT is attached to a scintillator via a bended light guide such that it covers the small side of the Čerenkov detectors. The light which is generated by incoming muons in the acrylic glass rod and the scintillator reaches their respective PMT where it is transformed into an electric signal that is amplified proportional to the deposited energy. The operating current of the scintillator PMT is -1850 V, the one for the Čerenkov PMT is -2050 V. (**Take note:** Photomultipliers are sensitive. Daylight must not reach them while they are turned on. Do not remove the insulating tape and do not open the cylinder.)

Both detectors are mounted such that they can be rotated around a horizontal axis. The measurement cone on the scintillator PMT shows the angle in degrees. The zero degree position is marked with a blue arrow. When adjusting the position, you have to take care that both detectors are aligned parallel to each other and the scintillator is still straight above the small side of the Čerenkov detector. (**Take note:** Do not push on the light guide**!**)

The goal is to measure those particles which enter at the chosen angle through the small face of the acrylic glass crystal. To achieve this, you measure what is known as the coincidence, i.e. you count whenever a signal arrives from the scintillator and from the Čerenkov detector at the same time. An important part of this is to choose the correct cable length. All LEMO cables are labeled with the time in nanoseconds that a signal needs to travel through them. If a particle flies through the set-up at the correct angle, it should first be detected by the scintillator, then by the Čerenkov detector. Accordingly, a longer cable delay must be used for the scintillator signal so that both signals arrive at the counting electronics at the same time.

This together with the fact that the PMT is situated at the opposite side of the Čerenkov detector lets you filter out particles that do not fall at the chosen angle.

Whether or not the coincidence is set up correctly can be checked with the oscilloscope.

2.1.2 Measurement electronics

The coincidence is a component which allows the application of logical operations on standardized input signals. The standard used is called NIM standard (Nuclear Instrumentation Module). However, you cannot expect a muon to keep to some standardized light pulse when flying through the measurement apparatus. This is why the PMT signals are first sent to a discriminator. This component transforms incoming signals which exceed a certain trigger level into a rectangular NIM standard signal of the same frequency. The coincidence then compares these two signals via a logical AND. Only if two signals reach the coincidence at the same time, it will send out a signal of its own. This signal will then be registered in the counting scaler. This is how you can determine the rate of incoming muons per time and angle.

2.1.3 Oscilloscope

The digital oscilloscope is used to measure and illustrate periodically occurring electrical signals. It provides two channels for recording signals, as well as one channel for an external trigger.

3 Hints and suggestions

In order to work out the angular dependence of the intensity of incoming cosmic muons, it is important to take at least eight measurements over a time of 24 hours per angle. Since the advanced practical course leaves you with a certain freedom about how to work with your experiment, the following bullet points should serve as suggestions.

- The theory part of the manual is sparse on purpose. You should research to deepen your understanding using common reference texts of experimental physics. (Gerthsen, Tipler, Wikipedia, ...)
- Cosmic muons are created at a height of about 10 km in the upper atmosphere. They have a mean lifetime of $2,2 \times 10^{-6}$ s after which they decay into electrons and neutrinos. What problem could this pose for a measurement at ground level? How can you explain that muons can still be measured with your set-up?
- You do not need to confine yourselves to using equidistant angles when selecting your set-up. You may want to look up the empirical angular dependence you can expect to measure. How could you choose your angles to show this dependence better?
- Get to know the different components of the detector. How does a photomultiplier work? How a scintillator?
- There is an oscilloscope at your disposal which can save pictures on a USB drive. Use it to look at the signals at different stages of processing. What is the purpose of the 50 Ω-terminated signal cable ports? Note that the oscilloscope has a bandwidth of 100 MHz. What does this mean for the measurement of the raw PMT signal?

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