Physics Lab

ETH zürich

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Instruction Manual

Advanced Physics Lab
Muon Life Time

Life Time Measurement of Cosmic Muons Stopped in a Large Block of Scintillating Material

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Abstract

In this experiment the life time of muons from the cosmic rays is measured. The cosmic rays interact with the atmosphere of the Earth where the muons are created. Due to their very low interaction rate they can reach the surface of the Earth.

The muon is stopped in a large block of scintillating material and life time is then measured as the time difference between the muon entering the system and the time the decaying electron or positron is detected. The resulting analogue signals are digitised with a desktop digitiser and recorded with a computer.

The goal of the experiment is set up a trigger logic to reduce the large number of background signals using elements from a NIM crate so the life time of the muon can be extracted from the data.

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1 Introduction

1.1 Cosmic Ray

Cosmic rays are a form of high-energy radiation, that mainly originates from outside the Solar System. There is evidence that a significant fraction of primary cosmic rays originate from the supernova explosions of stars.

Cosmic rays are composed of 99 % nuclei of atoms and 1 % solitary electrons. 90 % of the nuclei are from hydrogen and 9 % from helium, i.e. protons and alpha particles respectively. The missing 1 % are nuclei from heavier atoms. A small fraction of cosmic rays are stable particles of antimatter such as positrons and antiprotons. The energy spectrum is shown in Figure 1. Ultra-high-energy cosmic rays can reach up to 3×10^{20} eV which is more then seven orders of magnitude more than the particles accelerated by the Large Hadron Collider (LHC). This fact makes the Universe the strongest accelerators that exists and cosmic rays scientifically extremely interesting.

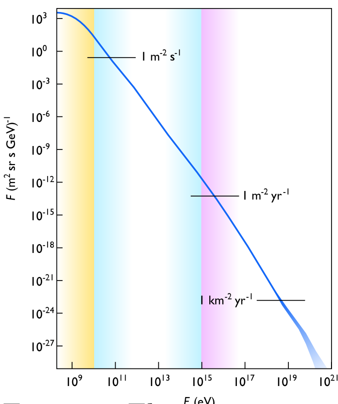

Figure 1: Flux vs. energy of cosmic rays.

1.2 Muon Production

When primary cosmic rays reach the upper atmosphere of the Earth, they collide with atoms and molecules, mainly oxygen and nitrogen. Upon collision a cascade of particles, a so-called air shower is produced which is shown in Figure 2. This secondary irradiation is mainly composed of x-rays, muons, protons, alpha particles, pions, electrons and neutrons, of which all stay within about one degree of the primary particle's path. The muons are mainly produced as decay products of the pions, which decay within in short distances of the order of meters. The resulting muons have velocities near the speed of light and due to their unusual low interaction rate with matter they can reach the Earth's surface.

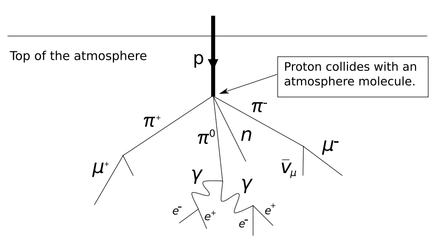

Figure 2: Primary cosmic particle collides with a molecule of atmosphere.

2 Setup

2.1 scintillators

The schematic setup of the scintillators is shown in Figure 3. The big block of in the middle is divided into the four sectors R1-R4 of which each is connected to a Photomultiplier Tube

(PMT). When a charged particle crosses the scintillator light is generated which is then guided to the PMT where is converted to electrons using a photocathode. These electrons are then largely multiplied to generate an electric signal, which is proportional to the amount of light generated in the scintillator. On top and below the block there the two pad-like scintillators Z_{top} and Z_{bot}, which are also connected to PMTs. They are used to trigger the interesting events.

A typical event is also shown in Figure 3, where the muon crosses Z_{top} and stops and decays into a positron the block segment R4.

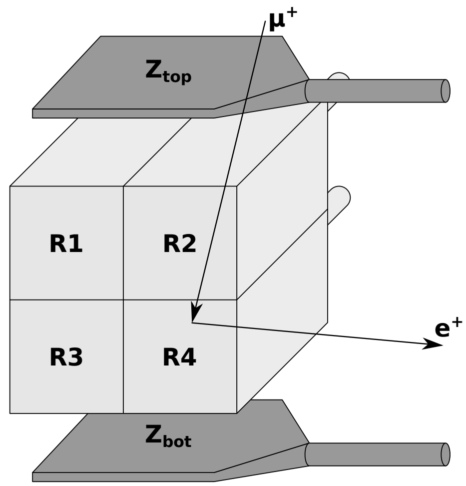

Figure 3: Schematic setup of the scintillators.

2.2 Control Crate

The second part of the setup is the control crate schematically shown in Figure 4. It consists of a WIENER CAMAC crate UEB 05/A with several sub-units, a SIN 415B High Voltage Power Supply and a SIN HV Distributor VD 003.

WIENER CAMAC crate UEB 05/A

CAMAC stands for Computer-Aided Measurement And Control and is a standard bus and modular-crate electronics standard for data acquisition and control used in particle detectors for nuclear and particle physics and in industry. The bus allows data exchange between plug-in modules (up to 24 in a single crate) and a crate controller, which can interface to a computer. There are several modules connected to the crate:

- LRS 621S Quad Discriminator (2)
- SIN OR 101
- SIN FC 101 Coincidence
- SIN FC 102 Coincidence

- SIN DT 102 D.Trigger
- Canberra Time Analyser Model 2143
- SIN S100 10 MHz Scaler

The signals from the photomultipliers are processed with the discriminators, which have a threshold of $30 \sim 1000$ mV. The threshold ("THRSH") is adjustable with a potentiometer screw (ten revolutions) and is set to the minimal value of 30 mV. The discriminators generate a norm (NIM) pulse with an adjustable pulse width ("WIDTH"). A width of 50 ns is sufficient for all following modules.

The OR unit generates a non-exclusive OR of the connected signals. That means that the unit issues a NIM pulse whenever one of the input signals is high. The width of the pulse can be adjusted with a non-terminated coaxial cable that is connected at "CLIP". A cable with a signal propagation time of 8 ns will lead to output signal of 16 ns width which is sufficient for the other modules.

The trigger can be generated with the FC 101 coincidence unit. This module will send out a NIM pulse if all activated ("ON") inputs are high and the "VETO" is low at the same time. The duration of the outgoing pulse is adjusted with a 8 ns coaxial cable at "CLIP" as well.

The D.Trigger unit will issue a NIM pulse after an adjustable delay ("DELAY") which has an also adjustable width ("WIDTH"). For this experiment a width around 12 µs is recommended. The unit will also issue a short NIM pulse when the 12 µs signal has ended.

In order to measure the life time of the stopped muon the Time Analyser is used. This module converts the time difference between the two inputs "START" and "STOP" to a analogue signal of $0 \sim 1$ V. The expected range of the time difference can be adjusted with a rotary switch. If the stop signal does not arrive within the set range there will be not output signal.

SIN 415B High Voltage Power Supply

The high voltage of the power supply can be adjusted with five rotary switches and should be set to -2180 V. The sixth rotary switch controls the polarity and must be set to negative. After switching on the device it needs about $20 \sim 30$ s to warm up before the high voltage is can be set to the two outputs on the back and the front of the device. Once the warm-up is finished the "STD BY" light will turn on and the outputs can be made active by switching the "HIGH VOLTAGE" switch.

SIN HV Distributor VD 003

The HV Distributor distributes the two incoming voltages from the power supply to ten outputs. The high voltage of each output can be individually adjusted in two different ranges. A digital display shows the current voltage for the selected channel, either one of the ten outputs or the two inputs. The high voltages for the individual photomultipliers are adjusted according to Table 1. The scintillators Z_{top} and Z_{bot} use different types of photomultipliers than the R1-R4. The high voltages of Z_{top} and Z_{bot} are adjusted so that the noise pulses are smaller than 25 mV and therefore smaller than the discriminator threshold of 30 mV. The

HV output	PMT	Range	HV
1	R1	1	$-2100\,\mathrm{V}$
2	R2	1	$-2100\,\mathrm{V}$
3	R3	1	$-2100\,\mathrm{V}$
4	R4	1	$-2100\,\mathrm{V}$
5	Z_{top}	2	$-1750\,\mathrm{V}$
6	Z_{bot}	2	$-1750\,\mathrm{V}$

Table 1: High voltages of the individual photomultipliers.

voltages of R1-R4 are set to the optimal working point of the PMTs. Their noise pulses are only $10 \sim 15\,\mathrm{mV}$. Due to that the spectra are almost free of background.

3 Experimental Procedure

The whole experiment should be already set up. Follow the following instructions to turn everything on:

1. all devices are supplied via a common power plug
2. turn on POWER on the High Voltage Power Supply → red light turns on
3. wait 30 s to let the device warm up → STD BY light turns on
4. turn on HIGH VOLTAGE from STD BY to ON
5. turn on POWER on HV Distributor → red light turns on
6. check if VOLTAGE on HV Distributor shows: -2100
7. turn on the CAMAC crate → BETRIEB turns on
8. turn on the computer

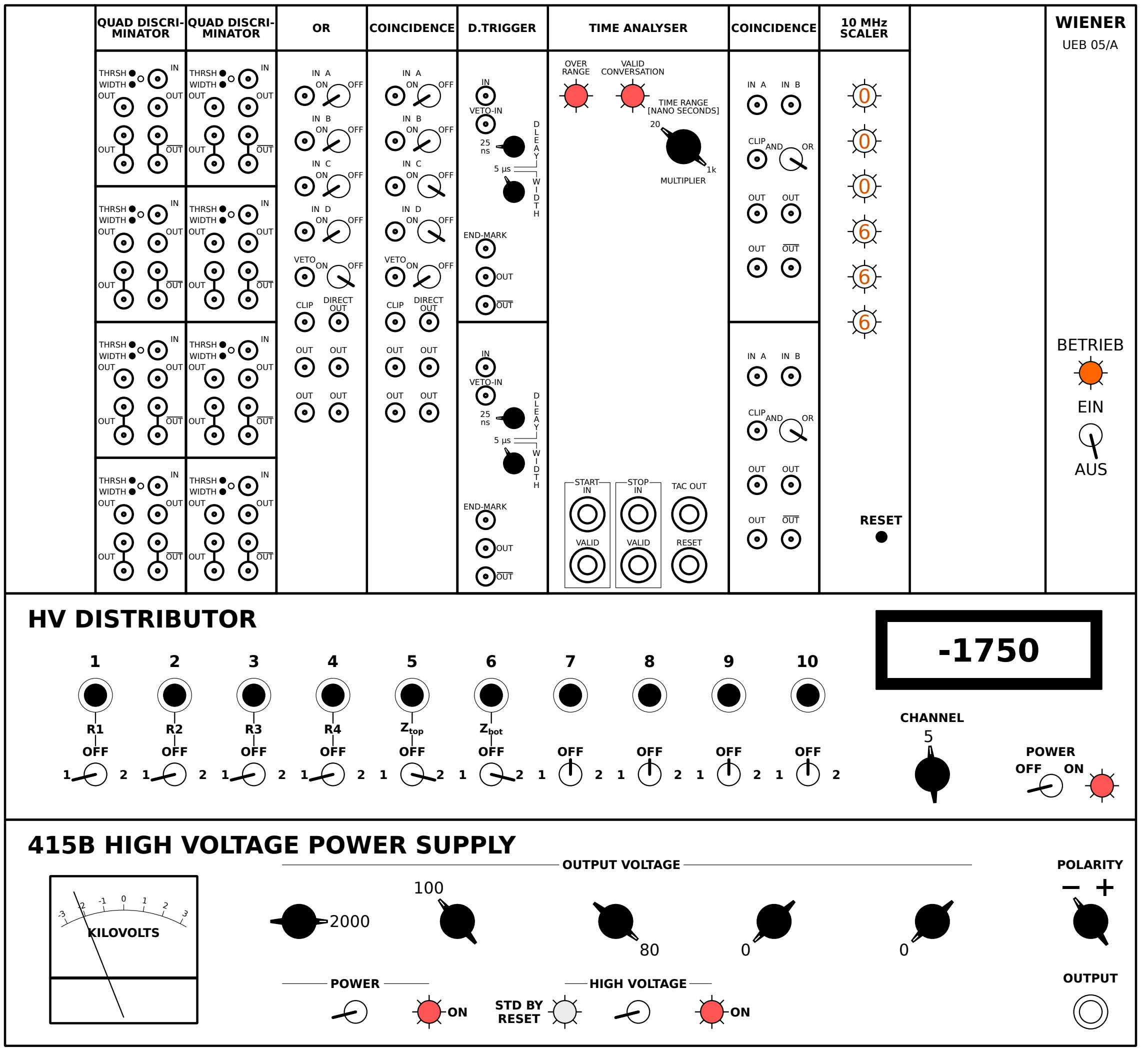

Figure 4: Schematic view of the control block.

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LHC Large Hadron Collider

PMT Photomultiplier Tube