V01 Lifetime of cosmic muons

Abstract

In this experiment the lifetime of cosmic muons is to be determined. A scintillation detector is used for this purpose. Understanding how it works and the interaction of the individual components of the setup is explicitly part of the learning objectives.

References

[1] C. Grupen, *Astroparticle Physics*, Springer (2020)

[2] H. Kolanoski and N. Wermes *Particle Detectors: Fundamentals and Application*, Oxford (2020)

[3] W. R. Leo *Techniques for nuclear and particle physics experiments*, Springer (1994)

[4] W. Walcher *Praktikum der Physik*, Teubner (1989)

Preparation

You should be able to answer the following questions in the colloquium.

- What are muons? What properties do they have? Where do cosmic muons come from? At what altitude do they arise? How do they decay?
- Explain the meaning of ‘lifetime´.
- Calculate the range of a cosmic muon ($E_\mu = 10\ GeV$) classically and relativistically as seen by an observer at rest on Earth.
- What event rates do you expect on the earth surface for these cases?
- What noise reduction techniques are applied? Estimate the remaining background rate U. Assume that the probability of another muon entering during the search time T_s is Poisson distributed and is triggering a stop signal.
- How does a multichannel analyser work and which quantities are plotted against each other in the observed spectrum? What shape of spectrum do you expect?
- What method is used to determine the lifetime of cosmic muons in the experiment? How is the basic measuring principle realised in terms of circuitry; what tasks are performed by the individual components? Get acquainted with the representation of logical compoents in ciruit diagrams.
- What is the “NIM-Standard” (**N**uclear **I**nstrument **M**odules)? Aquire a basic knowledge about “NIM-Modules”, “NIM Logic Signals”, “TTL Signals” and “ECL Signals”.

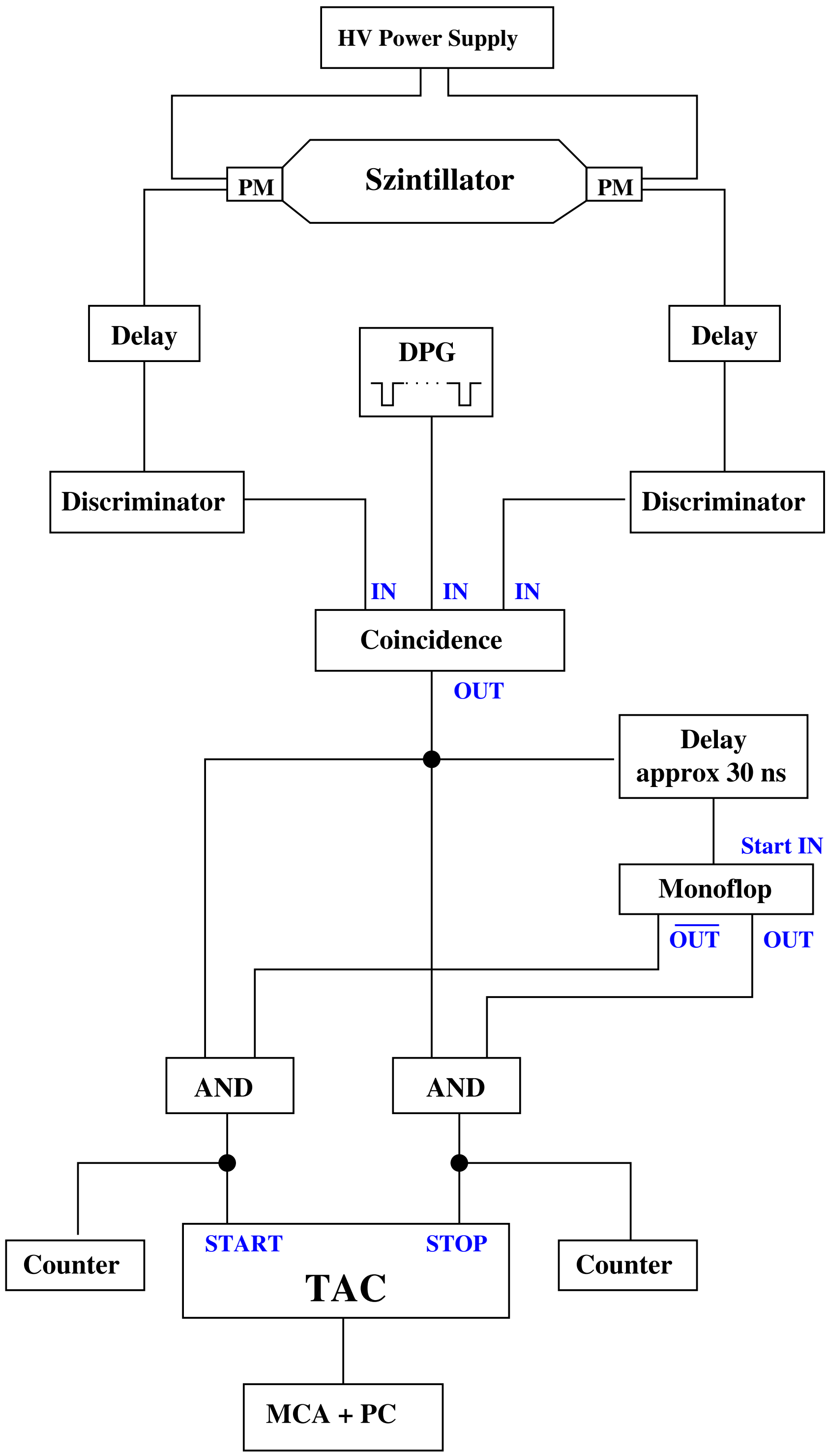

Figure 1: Experimental setup.

Experimental setup and adjustment

The experimental setup consists of a scintillator tank with an approximate volume of 50 l. **P**hoto**m**ultipliers (PM) are mounted at each end of the tank which detect the scintillation signals caused by a muon or its decay products. A combination of NIM modules allows the measurement of the time intervall between coincident muon and decay product signals. The outputs of the two PMs are given via a delay and feed in a discriminator with variable threshold. The duration of the discriminators output pulse is also adjustable. Both signals then enter a coincidence circuit, which only produces an output signal if the input pulses arrive at the same time. This is followed by the electronic equivalent of a stopwatch.
The output signal of the coincidence unit reaches two AND gates and, via another delay line of $\Delta t = 30\ ns$, a monoflop which sets the search time T_s. The AND gates are connected to the **T**ime to **A**mplitude **C**onverter (TAC) in such a way that one starts the time measurement while the other stops it. Two counters count the start and stop pulses, respectively. A suitable combination of components ensures that the time measurement starts when a muon enters the active volume. If the muon decays inside the tank, the measurement is stopped.
The signal from the TAC enters the **M**ulti-**C**hannel **A**nalyser (MCA), which is controlled by a PC. For calibration of the MCA, a **D**ouble **P**ulse **G**enerator (DPG) is available, which generates two pulses with a variable time interval at a frequency of 1 kHz.
If the PM are supplied with high voltage, voltage pulses with varying amplitudes should be visible at the respective outputs. Check this with the help of an oscilloscope.
In the next step, the threshold voltage of the discriminators must be set so that approx. 30 pulses per second are measured at both outputs. Set a pulse duration of $\Delta t = 10\ \mu s$. To do this, connect the pulse counter. To adjust the coincidence apparatus, systematically vary one of the delay lines and observe the pulse rate at the output of the coincidence unit. The measuring range should be large enough to determine the half-width of the distribution. Finally, select a suitable delay for the whole measurement. The event rate should be about 20 s^{-1}.
Connect the remaining parts of the circuit. Set a search time T_s, at the monoflop and adjust the measuring range of the TAC accordingly.
To calibrate the MCA, connect the double pulse generator and measure which time interval of the double pulses corresponds to which channel of the MCA. To check uniform efficiency over the entire measuring range, select the same measuring time for all measuring points and compare the absolute count rates.
After successful calibration start the measurement of the muon´s lifetime.

Measurement

Set up the circuit shown in Figure 1 and determine the lifetime of the cosmic muons from a series of measurements of individual lifetimes.