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CosMO – A Cosmic Muon Observer Experiment for Students

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Abstract: What are cosmic particles and where do they come from? These are questions which are not only fascinating for scientists in astrophysics. With the CosMO experiment (Cosmic Muon Observer) students can autonomously study these particles. They can perform their own hands-on experiments to become familiar with modern scientific working methods and to obtain a direct insight into astroparticle physics. In this contribution we present the experimental setup and possible measurements. The detector consists of three scintillator boxes. Events are triggered and readout by a data acquisition board developed for the QuarkNet Project. With a Python program running on a netbook under Linux, the trigger and data taking conditions can be defined. The program displays the particle rates in real-time and stores the data for offline analysis. Possible student experiments are the measurement of cosmic particle rates dependent on the zenith angle, the distribution of geometrical size of particle showers, and the lifetime of muons. Twenty CosMO detectors have been built at DESY. They are used within the German outreach network *Netzwerk Teilchenwelt* at 15 astroparticle-research institutes and universities for project work with students.

Keywords: atmospheric muons, scintillation detector, education, outreach.

1 Introduction

Cosmic particles of various types reach the Earth. They rain down constantly, some of them with energies much higher than the LHC reaches. Cosmic rays contribute to natural background radiation and produce the beautiful light of the auroras. Perhaps they also influence the formation of clouds and even the evolution of live. Although hundreds of these particles pass through us every second, most people do not know about this. Within *Netzwerk Teilchenwelt* [1, 2] we have developed the CosMO experiment to provide insights into this fascinating field.

CosMO is a scintillation counter experiment based on detector components that are used in particle and astroparticle physics. It can be operated by students on their own and brings the current topic of astroparticle physics to pupils who are interested in physics, astronomy, or computing. The project allows autonomous investigation and gets students involved in research. They are given the opportunity to experience hands-on science with the help of modern measurement techniques, as well as analysis methods in particle physics and in close collaboration with scientists. CosMO can be used in outreach projects at research institutes or within school teaching. Teachers receive training so that they are enabled to incorporate the CosMO experiment into their classes.

DESY and other partner institutes within *Netzwerk Teilchenwelt* lend the CosMO experiments for student projects and provide advise and support.

2 Detector Setup

The design goal of the CosMO detector was to develop an astroparticle-physics experiment that can be operated by students and that is easily transportable to be used at schools. The detector consists of three plastic scintillators. The scintillator tiles are connected to a data acquisition (DAQ) card with software-adjustable thresholds and coincidence conditions. A netbook computer is used to control the DAQ readout and to visualize the data. Figure 1 shows the full setup during operation.

Scintillator. We use plastic scintillator[1] tiles with a size of $20 \times 20 \times 1.2$ cm^3. The tiles are read out with 9 optical fibres each, which are connected to a multi-pixel photon counter[2] (MPPC), a type of silicon photomultiplier. The operating voltage of about 70 V for the MPPC is generated from a 5 V input voltage using an adjustable DC-DC converter[3]. The MPPC has the advantage that only low voltages are required for operation which are considered safe for students. The scintillator material and MPPC are housed in a lightproof aluminium box with connectors for the voltage supply and coaxial cable for the analogue MPPC output signal. The layout of the scintillator boxes is shown in Figure 2.

DAQ card. The DAQ card used is the version 2.5 data acquisition board [3] developed by a team of Fermilab, University of Nebraska, and University of Washington for the *Cosmic Ray e-Lab* [4] of the *QuarkNet* [5] project. Up to four analogue input signals are processed by discriminators with a software-adjustable thresholds. Each crossing of the discriminator threshold is

- recorded by a time-to-digital converter with a resolution of 1.25 ns (rising and falling edge),
- processed in a complex programmable logic device (CPLD) which forms a multiplicity trigger decision,

1. Ejen Technology EJ-200
2. Hamamatsu S10931-050P
3. iseg APn 02 255 5

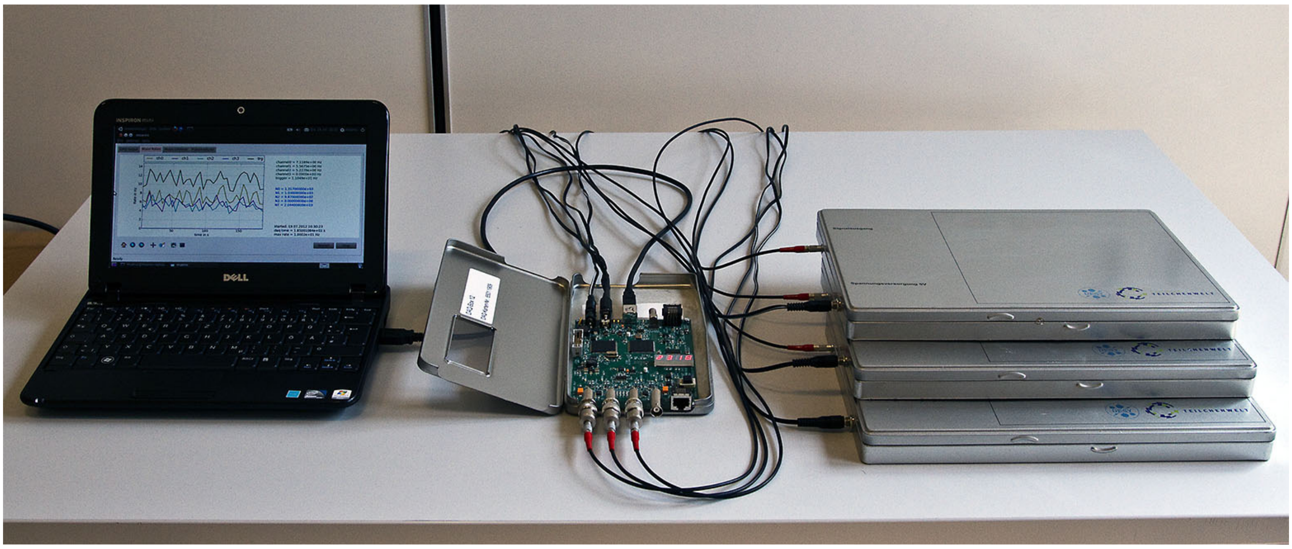

Figure 1: Overview of the CosMO setup in operation with three scintillator boxes (right), the DAQ card (center), and the readout netbook with the graphical user interface (left).

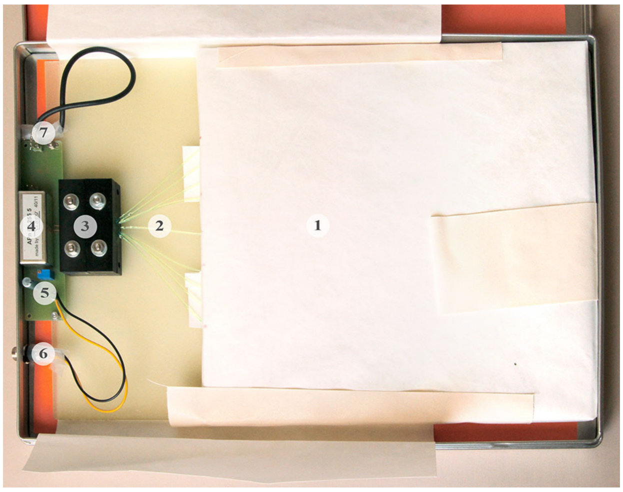

Figure 2: Overview of an open scintillator box: 1. plastic scintillator wrapped in paper, 2. optical fibers, 3. MPPC mounting, 4. voltage converter, 5. resistor for voltage adjustment, 6. connector for power supply, 7. analogue output for MPPC signal.

- counted in scalers for each channel.

The required multiplicity and the trigger time window can both be set in software. If the trigger condition is fulfilled an event is generated that contains a global timestamp and all threshold crossing times. In addition, a GPS module can be connected to the DAQ card that allows recording the global timestamp in UTC with a precision of 50 ns [6].

The DAQ card is powered with 5 V DC and offers the possibility to distribute its input voltage to the scintillator boxes so that the whole setup can be operated with a single main power supply.

Readout. The DAQ card provides a virtual serial port via a standard USB interface that makes it possible to access the data from a variety of different operating systems and programming languages. We developed software (cf. Sec. 3) specifically tailored to the CosMO project and running on a lightweight netbook computer.

The complete CosMO setup has a weight of about 5 kg and can be transported in a single briefcase, making it well usable in lectures, labs and outreach projects as well as in school projects. The detector can also be operated with a small 5 V battery pack, independent of the power grid.

3 Data Processing and Visualisation

Once connected with the netbook, DAQ communications are managed via a simple text protocol. The discriminator threshold crossing information is transmitted together with GPS and timing information via the USB interface. Commands can be issued to the DAQ card via the same interface.

To manage DAQ communications and visualize the data, we developed the software *muonic* [7]. As the main purpose of CosMO is the use for student experiments, the focus during the development of the software was to provide an easy-to-use interface. *Muonic* was developed entirely in Python, using PyQt4 for the graphical user interface (GUI). The software is written in a modular way, and can be extended easily. It is open-source and does not depend on closed source libraries. *Muonic* runs platform-independent and does not need an internet connection, which allows its operation in remote locations.

With *muonic* the user can set the DAQ configuration, like thresholds or trigger conditions by manipulating typical GUI elements. The software queries the DAQ for scaler information in a given time interval and displays this data as a simple rate per channel over time plot. Also the mean rate is calculated. The width of PMT pulses is displayed in a histogram for debugging and maintenance. The data stream from the DAQ can be stored in its raw format or as tab-separated values that can be imported into a spreadsheet. A screen shot of the GUI during a typical rate measurement is shown in Fig. 3.

Figure 3: Screen shot of the *muonic* graphical user interface during a typical rate measurement.

4 Projects for Students

4.1 Calibration

With *muonic* students can perform calibration measurements of the scintillation detectors themselves and thus gain deeper understanding of the physical principles involved. Evaluating the trigger rate vs. averaging time students can explore the influence of statistical fluctuations and determine the measurement time necessary to get a robust rate estimate. Analysing the single channel trigger rate vs. threshold will reveal the desired plateau of stable rates due to cosmic muons, bound by electronic noise towards too low thresholds and the absence of muon signals at too high thresholds. A typical calibration measurement is shown in Fig. 4. For each threshold setting approx. 5 minutes of data were collected.

4.2 Zenith Angle Dependence

A simple project for students to become familiar with the CosMO experiment is the measurement of the rate of coincidences as a function of the zenith angle, i.e. the suppression of the atmospheric muon flux with increasing atmospheric depth. At least two scintillation detectors are used in coincidence to suppress electronic noise and are placed in parallel to each other at a mutual distance d, which defines the solid angle from which particles are accepted. It has been shown that distances between 20 and 30 cm give a good compromise between restriction to direction of arrival and too low rates. The coincidence rate is measured using the *muonic* software and the measurement is repeated at different zenith angles. The students can be tasked to construct a setup that allows the rotation to well defined zenith angles while keeping the scintillator plates parallel to each other and at constant distance. The resulting rate as a function of zenith angle θ can be described by a $\cos^2\theta$ dependence [8]. Figure 5 shows a typical result plot for a scintillator tile distance of $d = 20$ cm and a measurement time of 1 h at each zenith angle.

4.3 Muon Lifetime

The CosMO detector allows a measurement of the mean lifetime of muons. Three scintillator boxes are stacked on top of each other. Decaying muons leave a characteristic signature in one of the channels, which are two pulses in a time interval, typically in the microsecond range. The first of these pulses is induced by the stopping muon, the second one by the electron created in the muon decay. To suppress coincident muon events, the downmost channel can be used as a veto.

To enhance the stopping power of the detector, students can test the influence of different absorber materials between the scintillation detectors. A histogram of the recorded time intervals can be fitted with an exponential function by the use of *muonic*, and the measured mean lifetime is displayed by the software. To gather enough statistics to be confident in the fit, a measurement time of about one week is required. However, the results of the measurement must be inspected carefully, since for some scintillators the results are affected by electronic noise. To suppress this noise contribution, very short time intervals can be excluded from the fit. The values of these time intervals can be set via a GUI element within *muonic*. The measurement of muon decay gives students insights into coincidence and veto techniques typically used in particle physics. This experiment illustrates also the measurement of statistically fluctuating quantities as well as the law of exponential decay. The measurement of muon lifetime also provides a good introduction into discussions about special relativity, because muons are only able to reach Earth's surface due to relativistic effects.

4.4 Further Possibilities

The CosMO detector further allows the study of absorption of air shower particles in different materials and to measure the velocity of muons. With three detectors in coincidence and arranged in a plane, extended particle showers can be measured. The versatility of the setup enables students to

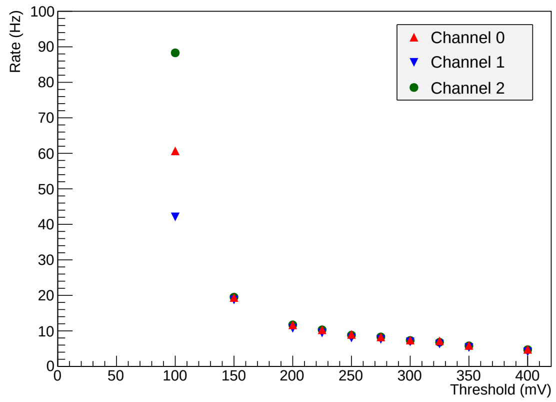

Figure 4: Single channel trigger rate as a function of threshold. The operating threshold for each scintillator is chosen on the plateau between 250 and 350 mV.

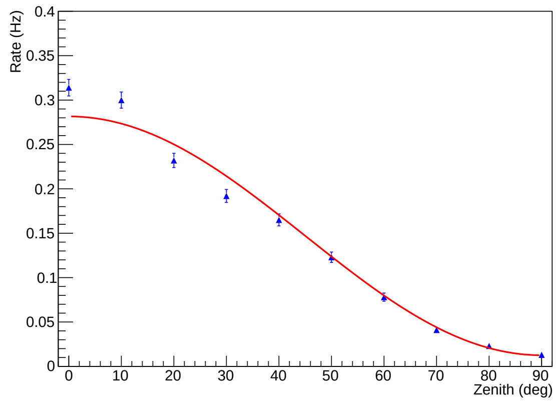

Figure 5: Measured muon rate as a function of zenith angle. To guide the eye, the curve indicates the expected [8] $\cos^2\theta$ dependence (including an offset for random noise).

learn about the acceptance of different detector geometries. With the stored data students can learn about statistical methods for analysing large data sets.

5 Netzwerk Teilchenwelt

Netzwerk Teilchenwelt [2] is a network of 24 German research institutes of astroparticle and particle physics with the goal to enable students to authentically experience modern physics research. More than 100 young scientists are active in the network and provide students and teachers with insights into their research in astroparticle and particle physics. Students and teachers experience the world of quarks, electrons and cosmic rays firsthand at workshops in schools, student laboratories, or museums all over Germany. As a scientist for one day, they analyse real LHC data in a masterclass. Within cosmic particle projects they perform own measurements. *Netzwerk Teilchenwelt* encourages discussion with scientists and diving into the world of smallest particles and the big questions about the origin and structure of the universe.

6 Conclusions and Outlook

The CosMO experiment enables students and teachers to explore the physics of cosmic rays in outreach projects or at workshops in school. They develop their own research project, analyse their own data, and discuss their results with professional scientists. This introduces students to the world of the smallest particles and to questions about the origin and structure of our universe. The hands-on experiments are currently extended by projects where the scintillation counters are installed at the German Antarctic research station Neumayer III [9] and on the German research icebreaker Polarstern [10] of the Alfred-Wegner Institute for Polar and Marine Research. These detectors take data continuously, thus enabling analyses over long time ranges with sufficient statistics. The major goal of the Polarstern project is to measure the dependence of the rate of cosmic rays on the geographical latitude, i.e. the geomagnetic cutoff. Furthermore, the influence of atmospheric pressure and temperature on the rate of atmospheric muons can be studied. On the Polarstern and at the Neumayer station additional neutron monitors are installed. All data will be made available on the internet to interested students and teachers and can be analysed together with the data from the CosMO detectors.

All these activities are implemented in and supported by *Netzwerk Teilchenwelt*. Everybody, no matter whether scientist, teacher, or student, is encouraged to become active and join us at *Netzwerk Teilchenwelt*.

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