Institute for Nuclear Physics, University of Cologne

Practical Course Master

experiment no. 3.2
Cosmic radiation

as at November 20, 2018

Abstract

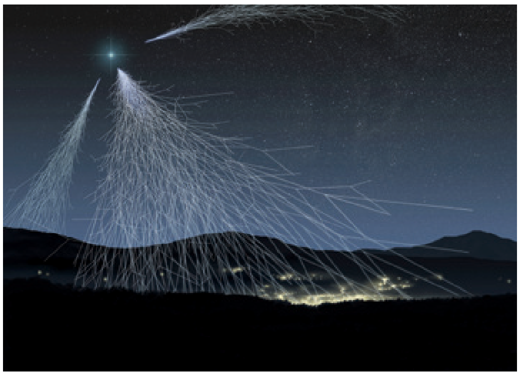
In this experiment cosmic rays are detected by a telescope consisting of two plastic scintillators. The intensity of the cosmic rays is analyzed for its dependence on the zenith angle, caused by the earth's magnetic field and the so-called east-west effect. To enable a measurement of this effect, the two scintillators are mounted on a rotatable frame and are operated in a coincidence circuit. The experiment focusses on important characteristics of cosmic rays and the earth's magnetic field as well as on a technically demanding setup.

1 Introduction

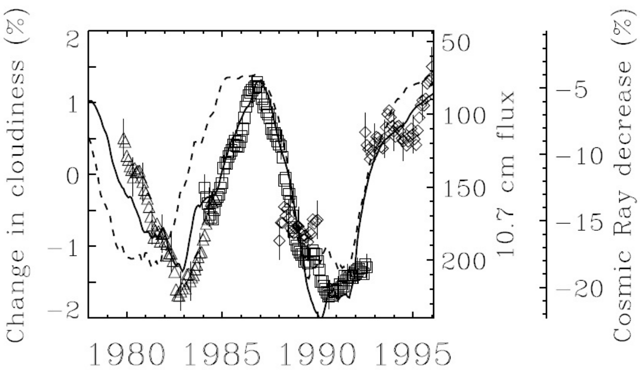
Permanently, our earth is bombarded by cosmic radiation, the primary component of these being light atomic nuclei. The energies of these highly-energetic particles are orders of magnitude larger than those reached in state-of-the-art accelerators. For instance, today's biggest, the Large Hadron Collider (LHC) at Cern, provides proton energies of up to several TeV (10^{12} eV). The highest energies observed in cosmic rays up to date are about 10^{21} eV. The secondary component, which can be observed on earth, is originating from collisions of the primary component with molecules of earth's atmosphere. An important part of this secondary component is the elementary particle muon. In this lab course the properties of the muon will be studied using plastic scintillators, modern data acquisition and the coincidence technique.

2 Basics about cosmic rays

In the early 20$^{\text{th}}$ century Viktor Hess discovered during his systematic studies an increase of ionizing particles with increasing altitude. He concluded that this "radiation" cannot originate from earth's surface and thus must be of cosmic origin. His experimental results were later on independently verified by physicist Werner Kolhörster and the working group of Robert Milikan. In 1936, Viktor Hess was awarded the Nobel prize in physics as the discoverer of the cosmic radiation.



(a)



(b)

Figure 1: **(a)** *Primary cosmic rays are inducing showers of secondary particles in earth's atmosphere [10].* **(b)** *Earth's cloud coverage (symbols) compared with the change in cosmic particle flux (solid line) und the variation of the 10.7 cm radio flux of the sun (dashed line) over a full solar cylcle [9].*

Today, the origin of the highly-energetic cosmic rays is still a controversially discussed topic in modern science. Shock waves of Supernovae explosions, particle jets of active galaxies as well as the decay of currently unknown elementary particles are thought to provide the acceleration needed to explain the highest observed energies of the primary component [10]. Moreover, at the end of the last century, Henrik Svensmark showed that cosmic rays might have a significant impact on earth's climate [9] (see also Fig. 1). In further publications Svensmark and Marsh proposed a mechanism how a sun-modulated flux of cosmic particles might influence low clouds [6, 7]. At these altitudes (about 16 km), muons and electrons are mainly the charged particles responsible for ionisation in particle collisions. It is the aim of this lab course to measure the muons which contribute to this component of ionizing particles. The detection of muons is a direct proof that those particles travel with roughly the speed of light. Otherwise, due to their short lifetime of about 2.2×10^{-6} s they would not reach earth's surface.

Due to different paths for different angles with respect to the horizon a characteristic angular distribution $N(\theta)$ of muons is expected [3]. Moreover, the mainly positive-charge character of the primary component of the cosmic radiation is the reason why a weak east-west effect is expected to be observed. Measuring the muon intensities for each angle θ in east and west direction, i.e. $N(\theta_{\mathrm{i,E}})$ and $N(\theta_{\mathrm{i,W}})$, the east-west asymmetry coefficient can be determined according to the following formula:

$$\epsilon = \frac{\sum_{\mathrm{i}} \left(N(\theta_{\mathrm{i,W}}) - N(\theta_{\mathrm{i,E}})\right)}{\sum_{\mathrm{i}} \left(N(\theta_{\mathrm{i,W}} + N(\theta_{\mathrm{i,E}})\right)}$$

The east-west effect is most pronounced at the equator and lessens towards the earth's poles with $\epsilon \approx 0$ already at latitudes around 50°.

3 Topics to be prepared by the students

It is highly recommended to prepare the following topics for the day of the lab course.

- **Primary and secondary component of cosmic rays:** Main components and energies of the primary component, structure of earth's atmosphere, formation of the secondary component, classification of secondary components, formation of cosmogenic nuclides

- **Angular distribution of cosmic rays, east-west effect**

- **The elementary particle muon:** leptons, properties

- **Experimental setup:** working principles of inorganic and organic scintillators, photomultiplier, discriminators (constant-fraction discriminator (CFD)), gate generators, and time-to-amplitude converters (TAC), as well as the basic principles of the coincidence technique

Figure 2: *The experimental setup consisting of two plastic scintillators mounted in a rotatable frame. In addition, a sketch of a possible muon trajectory is shown.*

4 Measurements

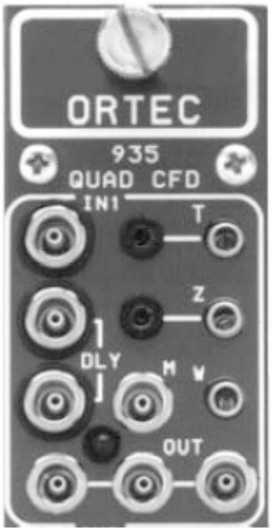
4.1 Setting up the detectors

Each photomultiplier has a power supply of 900 V which has already been preset. Make sure that each detector unit is connected to the power supply properly. **Do not switch on the high voltage before checking the connections. Please cross-check with the course instructor.** Connect the signal output to the oscilloscope and write down the signal's characteristics (rise time, decay time).

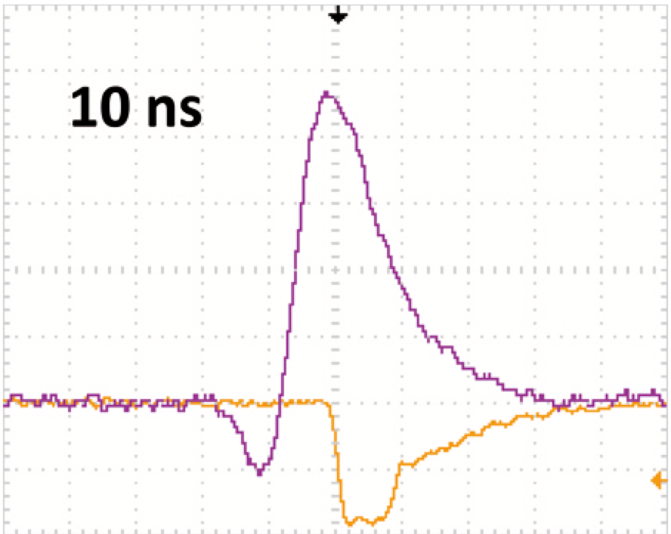
4.2 Adjustment of the thresholds and walk correction

To be able to measure muons, events stemming from background radiation have to be suppressed. This radiation has typically cut-off energies of several MeV. To achieve a higher count rate of such events, a ^{226}Ra γ-source is used.

The detector signal is passed on to the *constant-fraction discriminator (CFD)* (Ortec 935 [8], see Fig. 3 **(a)**). Connect the *CF Monitor (M)* and *logic output (OUT)* to the scope. After the adjustments you should obtain signals as shown in Fig. 3 **(b)**.



(a)



(b)

Figure 3: **(a)** *A single unit of the constant-fraction discriminator (CFD). See the text for explanations of inputs and outputs or refer to Ref. [8].* **(b)** *CF Monitor (M) output (purple) and logic output (OUT) (yellow).*

Before adjusting the threshold, you have to optimize the output of the CFD.

1. Attach a delay cable to *DLY*, which should have a length corresponding to the time needed for the signal to rise from 20% to full amplitude. The final *CF Monitor (M) output* should look like the purple signal shown in Fig. 3 **(b)**.

2. Next you have to perform the walk correction. Therefore, check the *CF Monitor (M)* and *logic output (OUT)* on the scope, while the trigger is set on the latter. Adjust the screw *Z* to obtain the same zero-crossing time for all CF Monitor signals. The width of the logic output should be adjusted to about 10 ns. You can use the screw *W*.

After these adjustments the CFD threshold can be determined. Start by placing the source in front of the photomultiplier tubes. An effect on the countrate should be clearly visible. A comparison of it with source and without source should be instructive. You can adjust the threshold with the screw *T* and monitor it with a multimeter. Choose the threshold such that no effect of the source on the countrate is observable. Be careful to not increase it too much as this will result in less statistics and longer measuring times.

4.3 Angular distribution of muons and east-west effect

To determine the angular distribution of the muons, the intensity of the muons is measured as a function of the zenith angle of their trajectory. Therefore, the measurement setup consists of two scintillation detectors mounted on a rotatable frame (cf. Fig. 2). The frame is aligned in north-south direction. Hence, the detectors are pointing to the east or to the west and the detection angle is defined by the connecting line between both detectors.

Accordingly, coincident signals of both detectors have to be detected. To make sure that coincident signals are detected, a ^{22}Na source can be used. Two coincident 511-keV γ rays are emitted by the source at a relative angle of 180° to each other. If the source is placed exactly at the mid-position of the frame, the coincidence setup can be adjusted. However, to detect the 511-keV γ rays the threshold would need to be decreased significantly.
In order to keep the adjusted thresholds for the muons, another more pragmatic approach is applied to generate coincident signals. Assuming that the response time of both scintilators and photomultipliers are similar, remaining differences in the timing of the signals are mainly stemming from the employed electronics. These can be corrected for in the following way:

1. First of all the output of one photomultiplier is split into two signals, using a T-piece. The generated (coincident) signals are fed into the CFD. Make sure that you use the same cable lengths for both signals.

2. Pass on the logic outputs to the scope. Estimate the delay needed to obtain coincident signals. If necessary, apply an additional delay in the *delay module*.

3. The logic outputs are passed on to the *CAEN coincidence logic unit*. Select a double coincidence, applying an *AND*. Adjust the width (*WDT*) of the unit output *OUT* signal to 150 ns and connect it to the *CAEN scaler and preset counter timer*.

Remove the T-piece and reconnect both photomultipliers to the CFD. Again, make sure that both connecting cables have the same length. Start the measurement and measure the muon rate for several angles ranging from 0° to 90°. Each measurement should take 20 minutes.

4.4 Muon velocity

Despite their short lifetime, muons can be detected at sea level because they approximately travel with the speed of light. The following measurement will try to proof this accepted result.

To measure the relative time between coincident events in both detectors originating from one muon and, therefore, to determine the flight time between the detectors an *ORTEC time-to-pulse-height converter* (TPHC; also: time-to-amplitude converter, TAC) is used. In order to calibrate the TAC the split signal of one detector is used again to generate coincident signals. Proceed as follows:

1. The output of one photomultiplier is split into two signals, using a T-piece. The generated (coincident) signals are fed into the CFD. Make sure that you use the same cable lengths for both signals.

2. Make sure to observe coincident signals on the scope once you have passed the CFD logic output.

3. Connect one signal to the *delay module*.

4. Connect the other signal directly to the *START* of the TAC and the delayed signal to the *STOP* of the TAC.

5. Connect the *TPHC output* of the TAC to the *multi-channel analyzer (MCA)*, which is connected to the PC and measure at least five different delays ($\Delta t_{\mathrm{delay}} > 16$ ns) in order to determine a channel-time correlation.

Data can be acquired now. Remove the T-piece and reconnect both photomultipliers to the CFD. Again, make sure that both connecting cables have the same length. The upper detector will provide the START signal, while the lower detector will provide the STOP signal for the TAC. Make sure to choose a sufficient delay of the STOP path. The measurement will last about 12 hours. The second measurement will take place the next day. For the second measurement the frame has to be rotated by $180°$. Why is this necessary to determine the muon velocity?

5 Lab report

The report should roughly follow the structure of the manual. Please cover all topics presented in this manual. Furthermore, every result has an uncertainty which has to be discussed. The following quantities have to be determined and discussed:

1. the function to describe the angular distribution

2. the east-west asymmetry coefficient

3. the calibration function to obtain the channel-time correlation

4. the muon velocity

References

[1] Allkofer, O. C.:
Introduction to Cosmic Radiation
Verlag Karl Thiemig, Deutschland, München (1975).

[2] Grupen, C.:
Astroparticle Physics
Springer Verlag, Deutschland (2005).

[3] Helmholtz-Zentrum Dresden-Rossendorf:
Wie lässt sich die kosmische Strahlung nachweisen?
`http://www.hzdr.de/db/Cms?pOid=13182&pNid=2455`

[4] Knoll, G. F.:
Radiation Detection and Measurement
John Wiley & Sons, United States of America (2010).

[5] Krane, K. S.:
Introductory Nuclear Physics
John Wiley & Sons, United States of America (1987).

[6] Marsh, N. D.; Svensmark, H.:
Low Cloud Properties Influenced by Cosmic Rays
Physical Review Letters **85**, 5004 (2000).

[7] Marsh, N. D.; Svensmark, H.:
Cosmic Rays, Clouds and Climate
Space Science Reviews **94**, 215 (2000).

[8] Ortec®:
Quad 200-MHz Constant-Fraction Discriminator – Manual
`http://www.ortec-online.com/download/935.pdf`

[9] Svensmark, H.:
Influence of Cosmic Rays on Earth's Climate
Physical Review Letters **81**, 5027 (1998).

[10] Welt der Physik:
Kosmische Strahlung
`http://www.weltderphysik.de/gebiet/astro/kosmische-strahlung`

A Operating instructions

Operating instructions for electric powered equipment in the rooms for the practical course

Danger for people

Burns or death by high electric currents

Safety measures:

Pay attention that cables and plugs are not damaged and use them only in the way they are designed for.
In case of damage, or if you have the suspicion that they are damaged inform immediately your supervisor, do not try to repair anything yourself.
Use at maximum one extension cord and only for low powered equipment.
For equipment with large power consumption only wall outlets should be used.

In case of emergency:

Pull the mains plug.
In case of fire: Switch of all electrical equipment as far as possible.

First aid:

People who can give first aid are Görgen, Rolke, Rudolph, Thiel
In case of shock call immediately an emergency physician Tel. **01-112** (from any telephone in the institute, or mobile **112**)
Hospital for accidents: evangelisches Krankenhaus Weyertal.
In case of all accidents also the managing director of the institute has to be informed.
In case of a working inability of 3 or more days an accident report form available from the secretary has to be filled.
The first aid box can be found in the inner stairwell.

13/11/2014
Blazhev

Operating instructions for high voltage equipment in the rooms for the practical course

Danger for people

Instantaneous death by ventricular fibrillation

Safety measures:

Pay attention that cables and plugs are not damaged and use them only in the way they are designed for.
In case of damage, or if you have the suspicion that they are damaged inform immediately your supervisor, do not try to repair anything yourself.
Switch on the high tension only after the cables have been connected and switch it of before disconnecting.

In case of emergency:

Switch of the high tension
In case of fire: Switch of all electrical equipment as far as possible

First aid:

People who can give first aid are Görgen, Rolke, Rudolph, Thiel
In case of shock call immediately an emergency physician Tel. **01-112** (from any telephone in the institute, or mobile **112**)
Hospital for accidents: evangelisches Krankenhaus Weyertal.
In case of all accidents also the managing director of the institute has to be informed.
In case of a working inability of 3 or more days an accident report form available from the secretary has to be filled.
The first aid box can be found in the inner stairwell.

13/11/2014
Blazhev

Universität zu Köln	**Operating instructions**	**Nr.:** **Date:** 13.11.2014 Signature: A. Blazhev

for the rooms of the practical course / institute for nuclear physics

IDENTIFICATION OF SUBSTANCE

Lead bricks

Lead bricks packed in plastic foil can be touched without precautions.
They are very heavy, **put them only in places where they can not drop on your feet!**
If the foil is damaged please pay attention to the following instructions:

DANGER FOR PEOPLE AND ENVIRONMENT

Danger

Warning

May cause harm to the unborn child.

May cause damage to organs through prolonged or repeated exposure.

Very toxic to aquatic life with long lasting effects

Do not breathe dust/fumes/gas /mist /vapours/spray

Avoid release to the environment

SAFETY MEASURES AND RULES

Do not touch any lead brick with a damaged protective foil. If the foil is damaged or if you suspect that it is damaged please inform immediately your supervisor

Breathing equipment: In case of fire toxic metal oxide smoke can be released. Wear self contained breathing apparatus.

Protective equipment: If the protective foil is damaged, lead brick must be touched only with protective gloves**.**

IN CASE OF ACCIDENT

Fire brigade 01-112 from any phone, mobil 112

Leave the contaminated area and inform your supervisor. If lead dust has to be removed wear always safety glasses, protective gloves and in case of large quantities a breathing apparatus.
Fire extinguishing measures have to be taken according to the surrounding materials.
In case of a fire dangerous fumes are generated. Please take actions according to the emergency action plan. Call the fire brigade. Lead must not get in the sewage system.

FIRST AID

emergency physician 01-112, mobil 112

After eye contact: Rinse opened eye for several minutes under running water. Then consult doctor.
After skin contact: Instantly wash with water and soap and rinse thoroughly.
After swallowing: Seek immediate medical advice.
After inhalation: Supply fresh air. If required provide artificial respiration. Keep patient warm. Consult doctor if symptoms persist.

First aid can provide: **Görgen, Rolke, Rudolph, Thiel**

DISPOSAL

Do not put lead in the sewage or the dust bin. Disposal has to be made via Dr. Blazhev or Bereich 02.2

Radiation protection directive for the handling of radioactive sources in the practical courses of the Institute of Nuclear Physics of the University of Cologne.

Issued 13/11/2014

1. Admission restrictions

Persons under the age of 18 years are not allowed to work in the practical course.

Pregnant women must not work with radioactive sources or in rooms in which radioactive sources are located.

Only students who have filled the registrations sheet and participated in the radiation protection instructions are allowed to carry out experiments with radioactive sources in the rooms of the practical course under the instruction of a supervisor. Visitors must not enter the rooms of the practical course when radioactive sources are located there.

2. Handling of radioactive sources

The radioactive sources are put in the experimental setup or in the lead shielding nearby by a radiation protection officer or an instructed person before the beginning of the practical course. These people document the issue in the list which is placed in the storage room (see appendix B). If radioactive sources have to be transported to other Physics institutes of the University of Cologne a list according to appendix A has to be attached to the transporting container.

When the practical course is finished the same people bring the radioactive sources back to the storage room.

A sign „Überwachungsbereich, Zutritt für Unbefugte verboten“ which means „monitored in-plant area, admission only for authorized personnel” has to be attached to the door of a room of the practical course when radioactive sources are inside.

It is not allowed to remove radioactive sources from the rooms of the practical course without contacting the radiation protection officer before.

During the practical course the radioactive sources must only be located at the place necessary for the measurements or behind the lead shielding nearby the experimental setup.

If you leave the rooms of the practical course make certain that doors are locked and windows are closed, even if you only leave for a short time.

Alpha-Sources are built in the experimental setup and students are not allowed to take them out.

Beta-Sources must only be handled by protective gloves or tweezers.

3. What to do in case of emergency

Any damages or suspected damages of radioactive sources must immediately be reported to the supervisor or the radiation protection officer. It is not allowed to continue work with such a source. Contaminated areas should be cordoned off immediately.

In case of fire, explosion or other catastrophic events besides the managing director and the janitor a radiation protection officer must be called in.

4. Radiation protection officers

Radiation protection officers for radioactive sources in the Institute for Nuclear Physics of the University of Cologne are:

Name	Heinze	Fransen	Dewald
Responsibity	Practical course	Experimental halls, work with radioactive sources, except of the practical course	Work in other institutes, Transport of radioactive sources, accelerator