The angular distribution of secondary cosmic rays

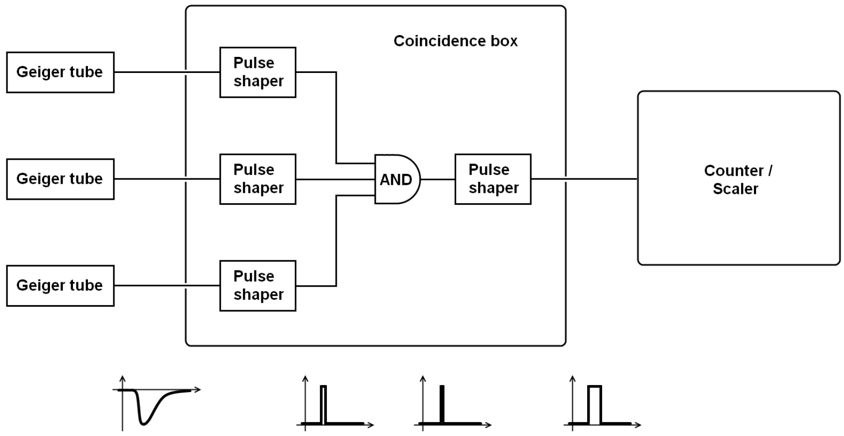
Number	138980-EN	*Topic*	Particle physics, cosmic rays				
Version	2017-10-03 / HS	*Type*	Project / long-running measurement	*Suggested for*	grade 12+	*p.*	1/4

Objective
Establishing a curve for the angular distribution of muons in the cosmic radiation.

Principle
A line through two (or three) Geiger tubes defines the direction of the incoming particles. By placing a thick absorber between the tubes we ensure that only highly penetrating radiation is detected.

The first measurements of the angular distribution were done in the 1930’ies, shortly after the invention of the coincidence circuit.

Equipment
Myon observatory
Geiger tube with large area (Qty. 2 to 3)
Coincidence box
Geiger counter
(Possibly datalogging equipment)



The coincidence box
The signal from each of the three Geiger tubes pass a circuit that shortens the pulse width to 1 µs.

The three signals are then joined in an AND gate and only if all three are active *simultaneously*, the output of the AND gate is activated.

The pulses from the AND gate output are given a suitable width (45 µs) before exiting the box.

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Setting up and checking equipment

Place the setup where it can be left undisturbed for the time measurements are performed.

Place all absorber plates in the magazine and tighten the holder against the plates.

Place two or three saddles on the rail. One of the se must be placed behind the absorbers, the rest in front of them. Place the Geiger tubes with their axis perpendicular to the rail.

Using two Geiger tubes is sufficient if you can accept the occurrence of one or two false coincidences during the experiment. With three tubes the probability of this is completely negligible.

Larger distance between the outermost tubes will of course lead to more precise angles – but this is at the expense of the count rates. The photo on p. 1 shows a setup that will result in very low counts – a shorter distance is clearly recommended.

Let the rail point vertically up (θ = 0°), and tighten the handle.

Connect each tube to an input on the coincidence box.

The coincidence count rate is very low, so we must check the setup carefully before measurements begin:

Connect the output from the coincidence box to a Geiger counter – this is the simplest way to do the initial check (even if datalogging is used later). Set the counter to count continuously and start it.

On the coincidence box: Set all three slide switches at *Disable* initially.
Setting **one** switch at a time at *Enable*, check that the background radiation that makes the LED flash now and then is also registered by the counter.

After that, possible datalogging equipment can be connected. We recommend the free program *Datalyse* (download English version from dtalyse.dk) which works well with Geiger counters 513600 or 513610.

In order to be totally sure you can repeat the check of one of the individual inputs.

Procedure

Place all three switches in the *Enable* position.

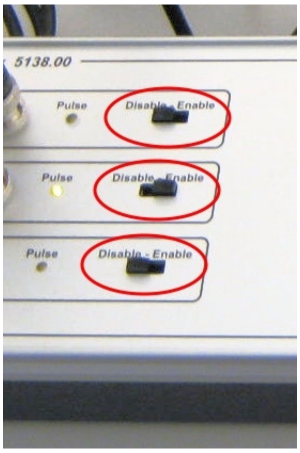
Zero the counter. Start the measurement. Wait approx. 24 hours.

Write down the angle (initially 0°), the counting period and the count.

Turn the rail to a new angle, e.g. 15°.

Start a new 24 hour measurement.

Continue until the rail is horizontal.



Checking input 2

Data processing

As you know, the uncertainty on the raw count *N* is given by $\Delta N = \sqrt{N}$.

Calling the counting period *T*, the counts can be converted to count rates with the expression

$$r = \frac{N}{T}$$

… with the associated uncertainty

$$\Delta r = \frac{\Delta N}{T} = \frac{\sqrt{N}}{T}$$

The uncertainty on the zenith angle will be maximum

$$\Delta\theta = \arctan\left(\frac{D}{L}\right)$$

where *D* is the effective diameter of the Geiger tube and *L* is the distance between the two (outermost) tubes.

(Frederiksen's Geiger tubes 512525 and 513565 have effective diameters 28,6 mm.)

Plot the count rates as a function of the zenith angle θ.

Draw the uncertainties of the count rates as vertical line segments above and below each data point. Similarly, draw the uncertainty on the angles as horizontal line segments.

(A spreadsheet can be used to draw these "error bars".)

In the same coordinate system, plot the graph of

$$f(\theta) = K \cdot \cos^2(\theta)$$

– with a suitable value of *K* that makes curve fit the data points near θ≈0 as well as possible.

Comment on the result.

Theory

The precise angular dependency will depend on e.g. the momentum spectrum of the muons at their creation in the upper atmosphere. A complete treatment is rather complicated.

However, it is possible under certain assumptions to show that the intensity at the zenith angle θ is approximately proportional to $\cos^2(\theta)$.
This dependency takes into account that the muons decay on their way down through the atmosphere – if this is neglected, a more "broad-shouldered" distribution is obtained (approx. 30% higher values at 45°).

The exponent on the cosine factor is not necessarily exactly 2 – often a slightly higher value (like 2.16) is seen.

Read more in Haymes' article (see literature list).

Note that when measuring very close to horizontally, the detector is sensible to particles from both sides, leading to counts in this area that are up to a factor of 2 too high.

Facts on muons

Muons exist as both positively and negatively charged particles (μ^+, μ^-). A muon is approx. 200 times heavier than an electron. Muons are unstable with a half-life of 2.197 µs.

Muons behave like electrons, but caused by the mass difference, the radiation length for muons is approx. 200^2 = 40,000 times larger than for electrons.

Muons from the cosmic radiation that reaches the sea level has an average energy of approx. 4 GeV.

The energy loss by ionisation of muons is relatively constant 2 MeV per g/cm^2. The thickness of the atmosphere is approx. 1000 g/cm^2, meaning that muons must be produced with an average energy of approx. 6 GeV.

Literature

Robert C. Haymes: *The zenith angle variation of cosmic ray mu meson intensity*

- can be found here:
www.dtic.mil/dtic/tr/fulltext/u2/032471.pdf

A biography of Bruno B. Rossi (inventor of the coincidence circuit) can be found on Wikipedia:

http://en.wikipedia.org/wiki/Bruno_Rossi

Coincidence measurements and random coincidences is treated in

Peter Dunne: *Demonstrating cosmic ray induced electromagnetic cascades*.

- can be found here:

http://hst-archive.web.cern.ch/archiv/HST2000/teaching/expt/muons/cascades.htm

Teacher's notes

Concepts used

Uncertainty of measurement

Mathematical skills

Graph plotting with error bars

About the equipment

The Geiger tubes specified can be substituted by 2 or 3 pcs. of 513565 Geiger sensor, large area, Jack – as long as the two types are not mixed.

The specified Geiger counter along with the associated communication cable can be substituted by a similar counter or datalogging equipment. The coincidence box is provided with a cable that also fits for instance Pasco's digital adapter.

You may consider to add a cheap UPS to the setup in order to avoid mains drop-outs to affect the measurements.

Random coincidences

In coincidence measurements, *random coincidences* appear as a kind of "background radiation" that you normally need to account for. The count rate of random coincidences for two channels is given by

$$r_R = 2 \cdot r_A \cdot r_B \cdot \tau$$

And similarly for three channels

$$r_\mathrm{R} = K \cdot r_\mathrm{A} \cdot r_\mathrm{B} \cdot r_\mathrm{C} \cdot \tau^2$$

Where r_A, r_B and r_C are the count rates for the three inputs, τ is the pulse width (10^{-6} s), and K is a constant in the order of magnitude 1 (that depends on experi-mental details).

With count rates for the individual inputs in the order of 0.5 s^{-1}, a random coincidence will happen once every 10^5 years for three channels while in a two-channel setup you will get 10-20 per year.
In both instances the random coincidences can safely be ignored.

Detailed equipment list

Specifically for the experiment

514200	Myon observatory
513800	Coincidence box

Standard lab equipment

512525	Geiger tube, large area (Qty. 2 or 3)
513610	Geiger counter (or older model 513600)
512565	USB communication adapter for 513600