The Roland Maze Project; Single Muon Flux Measured with the GM Telescope.

T. Wibig*‡, R. Kołodziejczak*† R. Pierzyński*† and R. Sobczak†
*A. Sołtan Institute for Nuclear Studies, Cosmic Ray Laboratory,
POB-447, 90-950 Łódź-1, Poland; (‡Univ. of Łódź),
†XII LO im. Stanisława Wyspiańskiego, Łódź, Poland.

***Abstract*— The group of high school students (XII Liceum) in the framework of the Roland Maze Project build the compact telescope of three Geiger-Müller counters which allows students to perform serious scientific measurements concerning single cosmic ray muon flux on the ground level and below. Their work is a excellent example of what can be done by the young people when respective opportunities are created by more experienced researchers and a little help and advice is given.**

I. Introduction

A. Cosmic rays

Cosmic Rays (CR) was discovered in 1912 by Victor Hess. In his balloon flights he found an increase of the discharge rate of an electroscope with a height of the balloon.

The electroscopes used in pioneering years of cosmic ray physics were replaced early by more sophisticated equipment, e.g., Geiger-Müller counters. The simplicity of Geiger-Müller (GM) counter makes it very useful not only for scientific purpose. The GM counters have been extensively used by astronauts to explore other planets in early s.f. movies, and even by James Bond in his first movie appearance in ”Doctor No”[1].

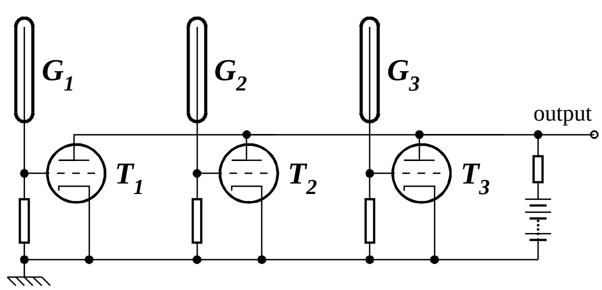

Fig. 1. Three-fold coincidence circuit by B. Rossi.

The GM counters used by B. Rossi around 1930 worked in a coincidence mode made by three electronic valves [2]. This significant electronic achievement of its times is shown in Fig. 1.

B. **The Roland Maze Project**

Extensive Air Showers (EAS) have been seen for the first time by Roland Maze with the apparatus build by him on the roof of Ècole Normale Supérieure in Paris. It consisted of three sets of GM counters (each of area of about 10×10 cm^2) working in different coincidence modes. In 1938 R. Maze and P. Auger announced the discovery of huge cascades of charged particles (EAS)[3].

Cosmic ray studies are recently intensively developed, especially in the region of the upper limit of energy spectrum, where several events involving cosmic ray particle with energy exceeding 10^{20}eV ($\approx$50 J) have been observed. Their existence is very serious physical problem. On the list of 100 Big Questions *”From the nature of the cosmos to the nature of societies”* published in the Science magazine in the text entitled ”So Much More to Know...” [4] it has number $4^{\rm th}$: *“Where do ultrahigh-energy cosmic rays come from? Above a certain energy, cosmic rays don’t travel very far before being destroyed. So why are cosmic-ray hunters spotting such rays with no obvious source within our galaxy?”*

The experimental setup for recording such events usually consists of number of relatively simple particle detectors spread over a large area. Nowadays a single detector is a scintillation (or Cerenkov) counter connected to the electronic system with a coincidence trigger and converters of time and amplitude of a signals to digital codes. The essence of large area experiments is a method of synchronization and communication between detectors and a system of collecting and storing the data.

This is the perfect point where high school education can meet the high science. It is hard to imagine another subject of such great importance which can be studied jointly by scientists and students. It is not surprising that at present there are related projects under constructions in USA [5] and in Europe[6].

One of them is the Roland Maze Project [7]. The EAS detection stations would be placed in buildings of high schools.

The detection system of one station (school) allows one to conduct (in parallel with the main scientific object of the project: studies of extremely high energy cosmic rays) independent observations and studies for each group participating in the project. It covers the whole, wide region of cosmic ray particle energies, giving the ability to study geophysics and atmospheric phenomena as well as monitoring the Sun’s activity and space weather from one side, up to the properties of typical EAS on the other.

We have gathered many students interested in making ”big physics”. The constructions of the Project detectors and all the systems is going on, but in spite of that, not to lose the initial impact, we proposed to the students many other activities.

II. Telescope of Geiger-Müller counters

One of many byproducts of the Roland Maze Project is the idea of making small cosmic ray detectors/counters which can be hung on the school wall showing to everybody that cosmic rays are everywhere and rising the interests to science in general.
The counters were decided to be telescopes of three Geiger-Müller counters working in coincidence. Such setup reminds the very first array of Maze and on the other hand exactly resamble the idea of the station (school) in the Roland Maze Project.

The telescopes are to be build entirely by groups of students from one school. The only part which can't be made by them are GM counters, which are made in A. Sołtan Institute for Nuclear Studies in Łódź. The counters are glass counters with external cathode. This kind of GM counters is called Maze type [8].

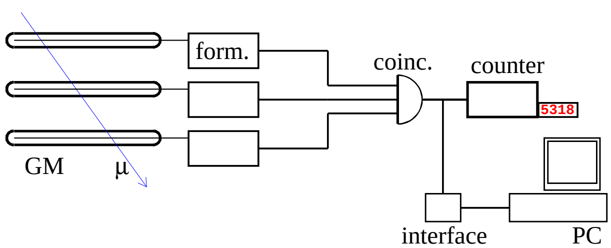

Fig. 2. The schema of the telescope of GM counters.

The electronic schemes of the particular circuits are also to some extent created by students, specially if there is one in the group with some electronic experience. If there is none, a general schema is given and the particular solutions are then to be found empirically. This leads to braking some electronic components, but eventually it leads to great satisfaction which is one of the more important factors when doing science and what is hard to explain to the students in other way.

A. Particular solution

The telescope of which results we want to present in this paper is made by students XII Liceum in Łódź.
The schematic view of the telescope is shown in Fig. 2.
The high voltage of about 1500 V needed to supply the GM tubes is created by the modified TV HV transformer with primary winding connected to simple pulse generator of 5-12 V and secondary to the Villard cascade. The coincidence was realized with standard TTL monostables with duration time of about 2 μs. The 4-digits 7 segment display of about 1 inch height was used to show the number of counts.

The telescope was equipped with the simple interface build on a base of the 555 circuit used to connect it to the PC class computer. The interface was originally programed under DOS in BASIC. The computer is able to continuously register telescope counts and to write them successively on the computer disk.

III. Results

A. Stability

In the Fig. 3 we show the number of counts registered every hour since beginning of the 2006 year to the end of January. As it is seen there are no abrupt (unexpected) changes, what cause us to state that the telescope is working properly and rather stable.

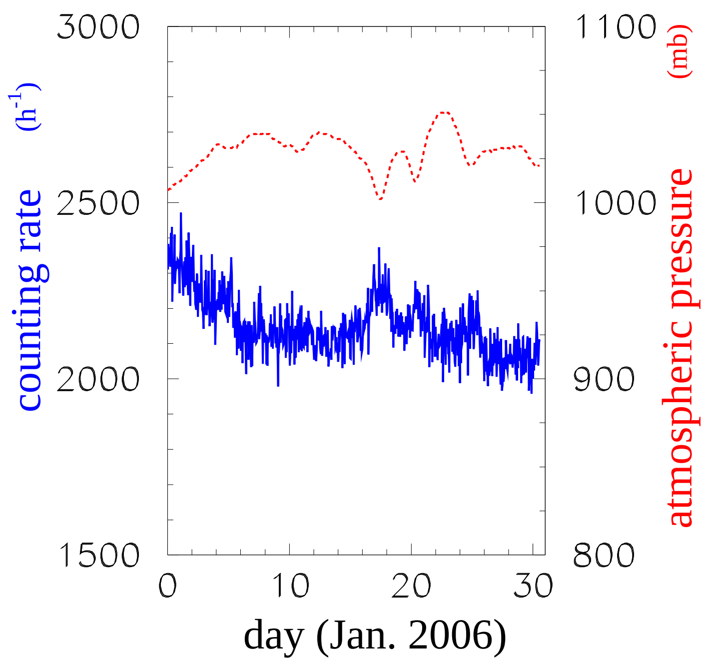

Fig. 3. The telescope counting ratio (solid line and left scale) and atmospheric pressure (dashed line and right scale) registered in January 2006.

B. Barometric coefficient

The single muon flux changes as it is known for a long time, since first CR stability measurements. The most pronounced modulation relates to the atmospheric pressure. The values of the pressure from local meteorological station were taken from the respective web page and they are plotted in Fig. 3. Fortunately, according the very rapid and substantial changes of the pressure in January 2006 the anticorrelation is clearly seen by necked eye.

To study it in detail in Fig. 4 we show the scatter plot of telescope counting rate vs. atmospheric pressure. The dashed line plotted there is the best linear fit.

To relate our result quantitatively to the values known from literature the barometric coefficient defined as relative change of the counting rate with respect to the increase of the pressure of 1 mb was calculated. Our result is -0.21$\pm$0.04%/mb.

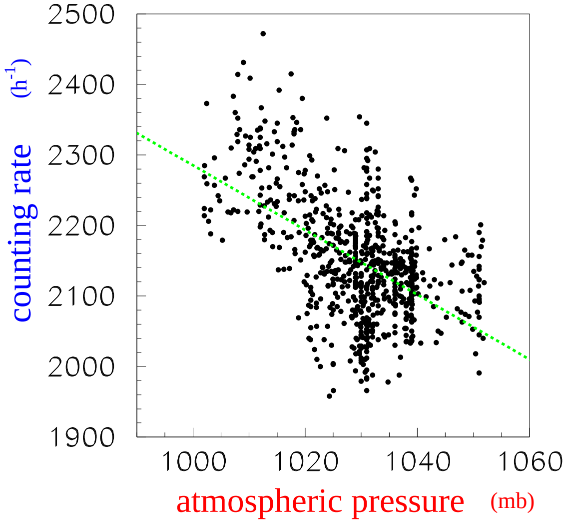

Fig. 4. Scattered plot telescope counting rate vs. atmospheric pressure registered in January 2005. Each point represents one hour counting results.

C. *Muon absorption in the ground*

The Łódź EAS array of A. Sołtan Institute for Nuclear Studies has the detection point in the underground laboratory placed 15 m below the ground level. It was designed to detect muons of energies above 5 GeV in the EAS. At present it is used as the site of the prototype of Łódź ”space weather station”. The GM telescope was placed there and the single muon flux measured for few days. The results are shown in Fig. 5

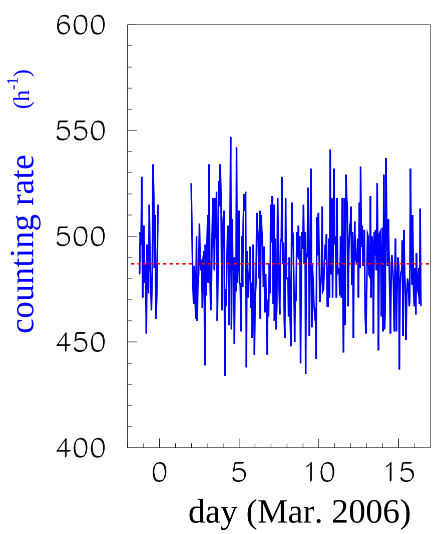

Fig. 5. Telescope counting rate underground.

Calculations show that muons which are able to reach the underground lab have to have energy greater than about 5 GeV. The measured decrease of the muon flux agree with this value.

IV. Discussion

A. *Main result*

The telescope made by high school students operating one month produced the data which allows students to determine precisely the value of the barometric coefficient as -0.21±0.04%/mb. This value is exactly what can be expected from the literature (-0.18 to -0.20%/mb.) confirming the principles of the methods and solutions used.

It is interesting to mention the work of Italian group [9]. The general idea was similar - to study the barometric effect with the help of simple computerized apparatus based on one small GM counter.

The known flux of vertical muons given by PDG [10] gives expected counting rate, and after simple geometrical integration we checked that it is consistent with our measured value (shown in Fig. 2).

B. *Significant achievements*

The value of the barometric coefficient itself, in spite of its correctness, is not the most important achievement of the present work. Few points have to be emphasized:

- students (R.K., R.P., and R.S.) designed the scientific instrument;
- students build it, checking, correcting and testing every part of it;
- students assembly all parts together making the fully operational apparatus;
- students parform measurements;
- students wrote analysis programs and analyze the data;
- students present their achievements on few occasions (starting from presentation given by them in a forum of their own class, presentation in Lodz high school competition on physics, presentation on ”3rd Roland Maze Scientific Session”, and recently on the National Competition of scientific works for high school students organized by Polish Academy of Science and INS, where they won first price).

The role of more experienced scientists (T.W.) participating in the telescope work should be also expressed precisely to avoid any suspicions (as we noticed in few occasions). First and obvious is to formulate the subject of investigations. Then the subject had to be introduced to the students in the way attractive enough to mobilize young people to get the job. Some help in electronics was of course needed. Specific questions concerning usage of elements to build up properly working circuits can be mostly answered with the help internet. Some personal help and assistance was necessary of course when testing built parts and assembling the telescope.

The construction process takes time. For this particular telescope this time was approximately one year. Students worked on the telescope in their free time, mainly on Saturdays, when they can spent their time without any collision with school duties. During this year students gathered not only abilities of making electronic devices, but in the meantime they improved their knowledge also on physics and on physics of cosmic rays in particular. To achieve this the assistance of more experience scientist was also important.

When the telescope was build the series of measurements were performed. The idea of what to measure comes naturally. The test of stability is obvious. The experimental setup produced number of files with huge (on the respective scale) amount of data. The interface and registration program was created in such way that each single registration was written to the disk. The help of the scientist was then necessary to put the attention of students to smooth changes of the counting rate seen in Fig. 2. This was also a good occasion to study foundations of statistics, e.g., the variation of the Poisson distributed random variable. The explanation of these changes as barometric effect also has to be introduced to the students. Then, after short lesson of the statistics (straight line fitting, χ^2 methods, etc.), students wrote their first programs in C and run them to get the result presented above.

C. Further planned measurements

The telescope can be used also to make other measurements among which the most obvious is to determine the zenith angle dependence of single cosmic ray muons. Studies of the temperature effect as well as searching for periodic muon flux variations (27 days, one day, semidiurnal to name only the shortests) are possible subjects of further interesting studies. The attractive subject is to looking for a correlations of CR flux with other phenomena, to mention only recent (2003) studies on influence of cosmic ray intensity on the wheat price in the medieval England [11]. The question if CR muons are correlated with average marks on school test, can attract to make "science" large amount of students.

V. Conclusion

We have shown that cosmic rays are as one of subjects of contemporary physics very useful to arise the interest on science among students of high schools. The present work proof that they are able to construct the apparatus which may be used to give quite accurate data on cosmic rays flux on the ground level. The value of the barometric coefficient can be obtained and other interesting studies can be performed. The analysis of that data gives perfect possibility for students be introduced to statistical methods on the level not available in standard courses.

The Geiger-Müller telescope hanging on a classroom wall and showing continuously number of muons crossing works well increasing horizons of minds not only of young people.

VI. Acknowledgments

We would like to thank Aleksander Mielczarek, a member of the Roland Maze Project who build the first working Maze GM telescope (at present student of the Łódź Technical University), for the valuable help in telescope construction and the software.

References

[1] `http:\\www.jamesbondmm.co.uk/q-branch/drno-gadgets.php`.
[2] B. Rossi, *Cosmic Rays*, McGraw-Hill, New York, (1964).
[3] P. Auger, R. Maze, T. Grivet-Meyer, *Comptes rendus*, **206**, 1721 (1938).
[4] D. Kennedy and C. Norman, Science **309**, 78 (2005); `http:\\www.sciencemag.org/sciext/125th/#online`.
[5] `http:\\csr.phys.ualberta.ca/˜alta`, `http:\\www.phys.washington.edu/˜walta`, `http:\\www.chicos.caltech.edu`, `http:\\physics.unl.edu`, `http:\\faculty.washington.edu/˜wilkes/salta`, `http:\\www.phyast.pitt.edu/˜jth/CosRayHS.html`, `http:\\www.hep.physics.neu.edu/scrod`, `http:\\www.phy.bnl.gov/˜takai/MariachiWeb`.
[6] `http:\\www.hisparc.nl`, `http:\\www.hisparc.nl/eurocosmics.php`, `http:\\hep.ph.liv.ac.uk/˜green/cosmic/home.html`, `http:\\www.particle.kth.se/SEASA`.
[7] J. Gawin *et al.*, Acta Physica Polonica **B33**, 349 (2002); `http:\\maze.u.lodz.pl`.
[8] S. Michalak, B. Mowczan and A. Zawadzki, Acta Phys. Pol. **13**, 145 (1954).
[9] B. Famoso, P. La Rocca and F. Riggi ,Phys. Educ. **40**, 461 (2005).
[10] S. Eidelman *et al.*, Phys. Lett. B 592, 1 (2004); (URL: `http:\\pdg.lbl.gov/`).
[11] L.A. Pustilnik, L.I. Dorman, and G. Yom Din Proc. $28^{\rm th}$ Intl. Cosmic Ray Conf., Tsukuba, 4131 (2003).