

# The $\mu$ Net project: A status report

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**Abstract.**  $\mu$ Net aims at the deployment and long-term operation of an extensive school network of educational Cosmic Ray telescopes in the geographical area of Peloponnese. In the framework of  $\mu$ Net, an extended educational program will take place, encompassing educational activities for the construction, testing and operation of  $\mu$ Cosmics (microCosmics) detectors, as well as for the remote operation of cosmic ray detection stations and astroparticle physics experimental devices deployed at the Hellenic Open University (HOU) campus. A pilot run of the  $\mu$ Net project started in 2020 aiming at the deployment and operation of a small school network in the prefecture of Achaia. In this work we present the progress of the program to date and the feedback we have received so far from the students and the teachers participating in it.

*Keywords:* Cosmic rays, Astroneu, microNet, microCosmics, air showers.

## 1. Introduction

The benefits of involving students in cutting-edge research programs have been well documented in the international literature and are one of the demands of school curricula in modern education [1, 2, 3, 4]. In addition, Greek high school students are not taught Astronomy and Astrophysics, so there is a serious gap in knowledge that is now considered part of the scientific literacy that the high school graduate must possess [5, 6, 7]. Moreover, Greek students are not distinguished for their achievements in sciences, with their performance being below average, according to the criteria set by the OECD [8]. Eventhough Greek students express their desire to participate in cutting-edge research activities, especially in the field of astronomy and the universe [9], their experience to date is limited either to visits to research centers, as a short parenthesis of an excursion or to the attendance of short demonstration experiments, with their accompanying lectures. On the other hand, initiatives for the active involvement of teachers and their students in the experimental processes of particle and astroparticle physics (i.e. hands on activities, detector instrumentation etc) are emerging worldwide [10, 11]. Towards this direction, many universities and research centers around the globe, offer extensive educational programs based on the construction, installation and operation of educational cosmic ray telescopes in schools [12, 13, 14].

The Astroparticle Physics Group at the Physics Laboratory of the Hellenic Open University (HOU) has designed the  $\mu$ Net program which aims at the active involvement of high school students in experimental procedures of Astroparticle physics and especially in Cosmic ray physics. Specifically, the project aspires for the development and long-term operation of a Greek school network of educational cosmic ray telescopes ( $\mu$ Cosmics detectors [15]) that will be installed at high school laboratories in the geographical region of Peloponnese. In addition, the project



includes the development of remotely operated experimental devices and the utilization of the HOU extensive air shower array (Astroneu array [16]), in order to provide access to any high school, independently of its geographical position. The schools that will operate in situ autonomous air shower detection systems, as well as the schools that will operate remotely the Astroneu stations and the HOU experimental setups will constitute the  $\mu$ Net network, the 1st Greek school network of educational cosmic ray telescopes.

In this work we will present the status of a pilot run of the  $\mu$ Net project which is currently in progress and includes five schools in the wider area of Achaea. Due to the pandemic restrictions the in situ deployment of the detection stations was prohibited and consequently the remote operations of the telescope gained focus. We will also present the feedback we have received so far from the teachers and students involved, showing that the online training method as well as the remote operation of the telescopes were quite satisfactory and met the expectation of both teachers and students.

## 2. The $\mu$ Net pilot project

### 2.1. Cosmic Air Showers

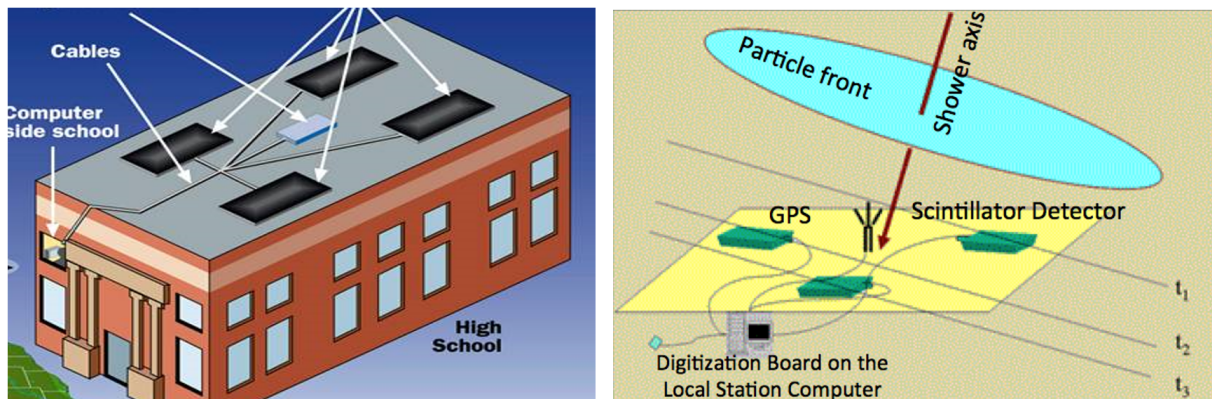
The earth is continuously bombarded by elementary particles and atomic nuclei of very high energies. Most of them are protons and all sorts of nuclei up to uranium (although anything heavier than nickel is very, very rare). Cosmic rays will hardly ever hit the ground level but will interact with a nucleus of the atmosphere, usually several kilometers high. In such collisions, many new particles are created and most of them being pi-mesons (pions). The number of these secondary particles starts to increase rapidly as this shower or cascade of particles moves downwards in the atmosphere. On their way and in each interaction the particles lose energy, however, and eventually will not be able to create new particles. After some point, the shower maximum, more particles are stopped than created and the number of shower particles declines. Only a small fraction of the particles usually comes down to the ground. How many actually come down depends on the energy and type of the incident cosmic ray and the ground altitude. Actual numbers are subject to large fluctuations. In fact, from most cosmic rays nothing comes down at all. Among these particles, the muons (atmospheric muons) are the most numerous energetic charged particles arriving at sea level, with a flux of about 1 muon per square centimeter per minute. These secondary cosmic rays constitute about one third of the natural radioactivity.

When a primary cosmic ray produces many secondary particles, we call this an air shower. When many thousand (sometimes millions or even billions) of particles arrive at ground level, perhaps on a mountain, this is called an extensive air shower (EAS). Most of these particles will arrive within some hundred meters from the axis of motion of the original particle, now the shower axis. But some particles can be found even kilometers away. Along the axis, most particles can be found in a kind of disk only a few meters thick and moving almost at the speed of light. This disk is slightly bent, with particles far from the axis coming later. The spread or thickness of the disk also increases with distance from the axis.

There are many detection techniques for these extended air showers: fluorescence detectors which measure the excitation of air molecules, Cherenkov telescopes that measure the electromagnetic component of the shower, radio antennas which measure the radio signal produced by energetic primaries, as well as scintillator counters and tracking detectors that detect particles at the ground level or even below. However, the most simple and common technique is the use of ground based sparse arrays of scintillators.

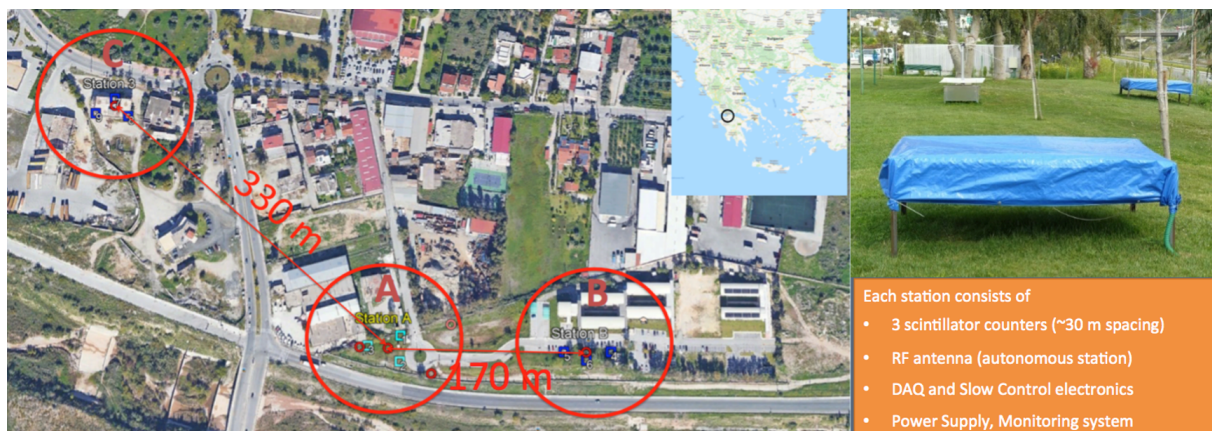
### 2.2. Educational Cosmic Ray Telescopes

A typical educational cosmic ray telescope (Figure 1-left) consists of three plastic scintillator detectors, read out by a digitization card. The detectors are placed a few meters apart and use the global positioning system to provide an absolute time reference. By requiring that three or



**Figure 1.** On the left: standard installation of atmospheric sprinkler detectors on the roof of a school building. On the right: reconstruction of the atmospheric shower direction.

more of the detectors to register particles within a narrow time window, one can distinguish between the relatively high flux of individual particles from low energy cosmic rays and the lower rate of extensive air showers, caused by higher energy primaries. Measuring the relative timing, as the shower particle front passes through the particle detectors and by triangulation, the direction of the shower axis and consequently of the primary particle can be reconstructed with an accuracy of a few degrees (Figure 1-right).

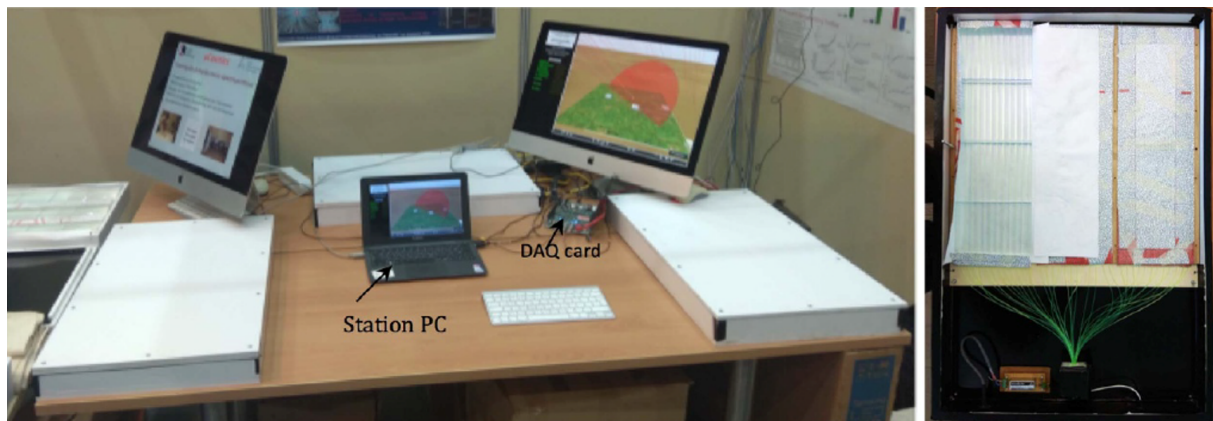


**Figure 2.** The Astroneu array in HOU campus

The idea of deploying such educational cosmic ray telescopes at the roofs of high school buildings originated in North America and now it is spread all over the world [13]. In Greece, the relevant project is called HELYCON[17] and it is based on the large scintillator detectors of the Astroneu array. Astroneu [16] is a hybrid EAS detection array installed at the HOU university campus. It consists of 9 scintillator detectors and 6 Radio Frequency (RF) antennas distributed in 3 autonomous Astroneu stations (Figure 2).

### 2.3. The $\mu$ Cosmics detector

One disadvantage of the Astroneu station to be used in a school project, is that it is massive, hard to move and quite expensive. In addition the roof of a school is not always available for detector deployment. To overcome this, the Physics Laboratory of HOU constructed a small-scale



**Figure 3.** On the left photo the components of the  $\mu$ Cosmics detector are shown. The internal structure of the detection unit (white box) is shown on the right photo. (Left) Reproduced from [15].

detector ( $\mu$ Cosmics detector) having one sixth of the area of the Astroneu station (Figure 3). The  $\mu$ Cosmics detector unit is very small, easy to carry, it weighs about 6 kilos and much cheaper than the large Astroneu detector. Also, it does not require high voltage or potentially hazardous power supplies. In addition, the  $\mu$ Cosmics detector can be assembled by students, while its small size and lightweight allows for many educational activities to be carried out in the classroom or in a school laboratory analogous to those developed for the HOU telescope [18]. The photo sensor of the detection unit is a Silicon PM which is of very low size and needs very low voltage of about 35 Volts. According to Monte Carlo studies with a threshold of 1 mip per detector unit, the rate of reconstructed showers is about 10 per hour, which is suitable for the duration of a lesson in the Lyceum.

#### 2.4. Educational activities



**Figure 4.** Students of the 2019 summer school in some of the educational activities with the  $\mu$ Cosmics detectors.

The operation of the  $\mu$ Cosmics detection system is linked to a series of educational activities, which have been implemented in two summer schools, that took place at the campus of HOU in 2018 and 2019 (in 2020 it did not take place due to the pandemic). These activities are presented very briefly in this work but for a detailed description see [18]. The activities in which students are invited to participate are: the assembly of a detector unit (Figure 4), the calibration and the measurement of the response of the detector to incident muons, the synchronization of the detection units, the measurement of the atmospheric muon flux, coincidence and geometry studies,

as well as data acquisition and online monitoring of the station, and finally, the measurement of the cosmic ray angular distribution. These activities introduce the students to the experimental process of astroparticle physics, revealing also to them invisible natural phenomena of the microcosm. In addition, the students comprehend that the scientific instrument is the tool that explores the physical processes of the microcosm and produces measurable electrical signals, that carry information on the physical characteristics of the macrocosm (Cosmic rays).

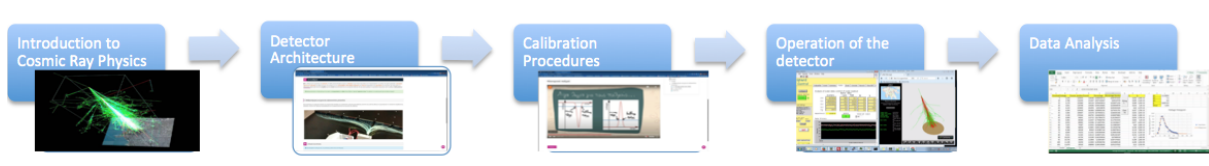
The students who participated in the summer schools were selected randomly and by invitation through the Directorate of Secondary Education of Achaia. The success of these two efforts and the experience we gained were utilized for the development of a pilot project, which is in full development, including five schools in the area of Achaia, where the Hellenic Open University is located.



**Figure 5.** The five air shower detection stations, located in the Physics Laboratory of HOU.

The plan of this pilot project was the deployment of the  $\mu$ Cosmics detectors at the 5 high schools and the enrolment of the students in these educational activities in person. Unfortunately, the COVID-19 pandemic did not allow us to follow exactly the original design. Since the schools were closed for most of the school period, we couldn't install the telescopes at the schools neither to train the teachers and students face to face. In order to overcome this, we built five detection stations, that were placed in the basement of the Physics Laboratory (Figure 5). Each telescope is controlled by a different computer and each school is responsible for operating the device it has undertaken, remotely. Moreover, we adapted most of the activities to be done remotely, while the training of the schoolteachers and students was completely carried out also remotely.

With these modifications the pilot program is currently in full swing, involving the five schools of the prefecture of Achaia. The online training is performed by simultaneous self-experimentation, using the experimental devices that are located at the HOU Physics Laboratory and are accessible via the internet. On their turn, the teachers have organized groups of students that will participate to the educational activities using the microCosmics detectors and at this stage of the project they are training them to the remote handling and operation of the telescopes. In this setup, each participating school is responsible for one dedicated cosmic ray telescope.



**Figure 6.** The workflow of trainees in the distance education program of the pilot run. Each task is supported by educational material (videos and animations) that are implemented to Moodle.

For the needs of distance education, detailed notes were written, covering both the Physics involved in the physical phenomena being recorded and the procedures to be followed when performing the roaming. Also, original videos were created, covering almost all aspects of the program, trying to be short and popular, without compromising on scientific accuracy. The workflow of the trainees is sketched on Figure 6 and it was implemented to a dedicated moodle-platform, After the removal of the strict restrictions due to the pandemic, there will be live meetings of teachers and students with members of our research team, where students will have the opportunity to see in person the detection devices.

### 3. Evaluation of the educational project

In our effort to improve the curriculum of the project and find its weaknesses, before it is developed on a large scale, we have constant feedback from the teachers and students through anonymous questionnaires. The participants were asked to answer to our questions, and five choices were given for each question, based on their degree of satisfaction and according to the following scale: 1 = “Not at all”, 2 = “A little”, 3 = “Partly/moderately”, 4 = “Very much”, 5 = “To a great degree”. Also, we kindly requested suggestions from the participants, in order to improve our ideas and practices for the future. From the feedback we received, we selectively present in the following Table 1 the percentages of the teachers that answered “very much” (4) and “to a great degree” (5) in some of the proposals in the latest questionnaire.

One of the questions we asked the teachers is from which class do they think that students can adequately respond to such a research project. In the first questionnaire 75% answered that the students of the 2nd Lyceum class (Grade 11) are the most suitable for such an education, while 25% thought that younger students but at least from the 3rd Gymnasium class (Grade 9) may respond in a very satisfactory level. Now the answers show that the majority thinks that students from the third class of Gymnasium can respond quite comfortably (40%). Concerning the distance education methodology, the teachers consider that the videos are one of the most powerful tools of the program and support distance education, however they believe that face to face learning for students is necessary (100%).

In Table 2, we selectively present the percentages of the students that answered “very much” (4) and “to a great degree” (5) in some of the proposals in the latest questionnaire. In the question “The educational material is modern and up to date” 83% of the students answered 5 (“to a great degree”) and the rest (17%) answered 4 (“very much”). A particularly pleasant surprise for us was the percentage of students (42%), that answered that they had also read the written material as well, eventhough the focus during the pilot run was given to the digital material.

### 4. Conclusions

Following the encouraging results of the two summer schools held at the HOU campus, the pilot implementation of the  $\mu$ Net project, which is underway in five schools in the region of Achaea, yields equally encouraging results. During the pilot phase of the project a complete

**Table 1.** The percentages of teachers that answered “very much” (4) and “to a great degree” (5) in some of the questions of the questionnaire

Question	4	5
How strongly do you think students’ interest in this program is maintained?	40%	60%
Do the theoretical requirements of such a project meet the capabilities of Secondary Education students?	100%	
How satisfactory is the audiovisual material developed for the students?	20%	80%
Do you think that working with students on a project of this type develops communication and interaction between students and teachers?	20%	80%
Do students adequately meet the requirements for computer use and remote control of laboratory systems?	40%	60%
Do you think that distance education works properly for such projects?	60%	40%
Do you maintain your interest in this project?		100%
Which videos and to what extent should be emphasized in order to make the program more attractive to students?	80%	20%

**Table 2.** The percentages of students that answered “very much” (4) and “to a great degree” (5) in some of the proposals

Question	4	5
Emphasis is placed on the practical application of knowledge	33%	54%
My expectations from my participation in the program are met	29%	54%
The program favours group and collaborative practice among students	21%	75%
The program meets the capabilities of students	48%	44%
Access to educational materials is easy	29%	63%
Do you think that distance education works properly for such projects?	85%	15%
Have you maintained so far your interest in the project?	21%	79%
The accompanying videos are detailed and understandable	28%	28%
The content of the program is complete and efficient (with respect to their expectation)	50%	50%

set of educational activities and educational material has been developed, while the in situ and remote operation procedures are established.

The  $\mu$ Net will be fully operational by 2023 and more than 1000 students per year are expected to participate. Currently, in the pilot phase of the project, approximately 50 students are involved coming from 5 high schools of western Greece. The pilot program is expected to be completed by the end of July 2021 following the distant learning methodology even if the pandemic measures are withdrawn. The feedback we receive from this pilot run, will be used to improve the remote experimental process, as in the next two years the project will be expanded in more than 50 schools in the Peloponnese. The experience to date is particularly encouraging, as students have

the opportunity to participate in cutting-edge research experiments, which are not offered at school, and to satisfy their personal interests, without having to leave their place of residence. In addition, distance education, with the logic of access to knowledge not available in the standard school curriculum, seems to work more democratically, as all stakeholders have access, regardless of where they live or their financial abilities.

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