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Cosmic rays at “Mercati di Traiano”

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Abstract

The work presented in this document is the result of an analysis carried out by students of the Liceo Scientifico "C. Cavour" using the Cosmic Box.The Cosmic Box is a small transportable cosmic ray detector that the school won in a competition organized by the Fermi Center in the framework of the EEE project [1].

The Extreme Energy Events (EEE) project is a research activity of the Fermi Center aimed at understanding the origin of cosmic rays hitting the Earth. The project involves many Italian high schools to bring young people closer to the world of science.

Cosmic rays are atomic nuclei from the cosmos striking the earth in different directions. The impact of a cosmic particle (mainly protons and helium nuclei) on the atmosphere produces a swarm of other particles that can be detected by instruments that study their nature of interaction with matter. After several studies, it was discovered that the number of cosmic rays changes as a function of altitude.

The measurements were carried out by the students of the Liceo Cavour at “Mercati di Traiano” (Trajan’s Market), an important archaeological site in Rome, in the various levels and rooms of the building. A greater number of cosmic rays have been detected by internal measurements than those of outer places and higher planes. The purpose of the work was to study the variation of cosmic rays according to the change of the height of the measurement’s location.

Introduction

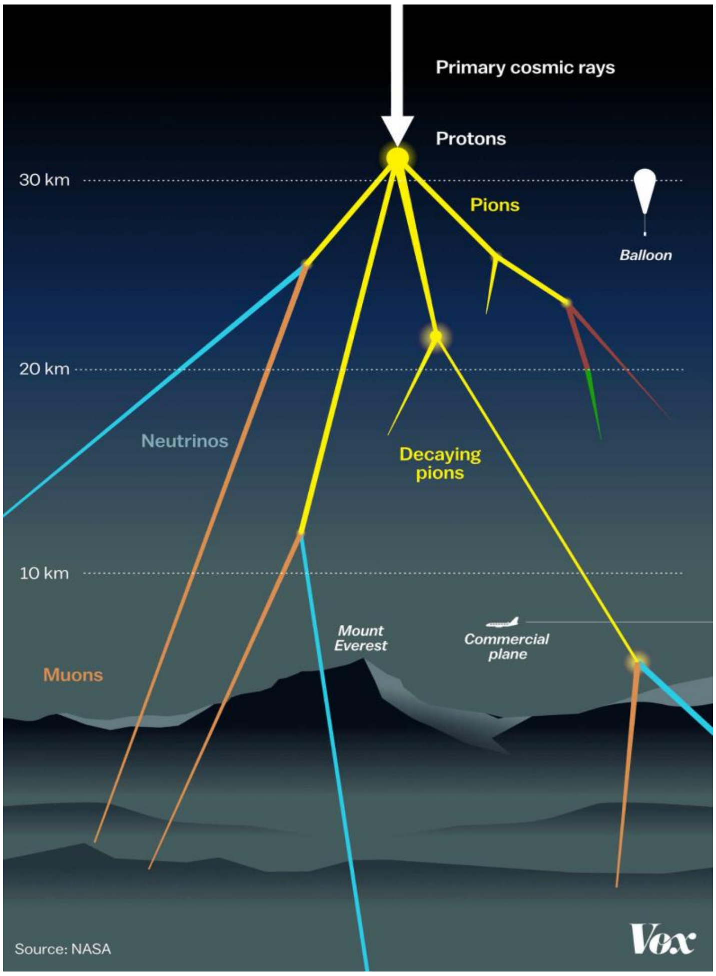
Cosmic Rays

Cosmic rays are high-energy particles and atomic nuclei traveling almost at the speed of light. They hit the Earth from all directions [2].

They are divided into primary and secondary rays: primary rays are those that reach our planet directly from their sources and enter the atmosphere, where they collide with air molecules. The secondary ones are those produced by the collision of the primary ones with the atoms of the Earth's atmosphere; this collision produces a swarm of particles that spreads out until it reaches the bottom of the Earth [3].

Primary cosmic rays include protons, neutrinos, electrons, nuclei of various types, and high-frequency photons. Secondary cosmic rays include electrons, neutrons, mesons, muons, and neutrinos. However, not all swarms reach the Earth: only the most energetic ones do.

Cosmic rays have different origins: the low-energy rays originate from our Sun and are produced by solar flares; the high-energy rays are produced much farther away: they could be originated from supernovae and other phenomena not yet known.



Source: NASA

Fig 1. Primary and secondary cosmic rays.

In the early years of the 20th century, scientists explained the discharge of an electroscope left in the air with radiation from small particles of radioactive material in the Earth: if this hypothesis were true, the radiation should have been more intense near the earth and become weaker with increasing altitude.

In 1910 Theodore Wulf, a German physicist used a new type of electroscope to monitor the ionization rate near the top of the Eiffel Tower. In 1912 Albert Glockel, another German physicist, used the same type of electroscope on board of a hydrogen balloon. Both observed that the discharge of the electroscopes did not decrease with the altitude as fast as expected. [4]

In the same years, the Austrian physicist Victor Hess carried out several studies with three electroscopes mounted on a hydrogen balloon. In 1911, after reaching an altitude of 1100 meters, Hess observed "no significant change in the radiation emanating from the Earth." On August 7, 1912, Hess measured the radiation rate at 5300 meters; it was three times higher than at sea level, from which the physicist concluded that the penetrating radiation entered the atmosphere from above. Afterwards the Sun was identified as the source of the radiation because no noticeable dips had been observed in an earlier flight during a partial solar eclipse: Hess had discovered a natural source of high-energy particles, namely cosmic rays. [5]

EEE Project

The Fermi Centre, together with the INFN (Istituto di Fisica Nucleare - National Institute of Nuclear Physics), conducted a special research study on the origin of cosmic rays as part of the "EEE-Science in Schools" initiative. High school students and teachers contributed significantly to this work.

In order to detect the cosmic muons and the expansion of the particle showers produced by the primary cosmic rays of higher energy, even as large as entire cities or more, a "telescope" with the most modern and advanced particle detectors (Multigap Resistive Plate Chambers, MRPC) was built on CERN (Conseil Européen pour la Recherche Nucléaire - European Nuclear Research Council) and placed in some of the participating schools. The data collected by each telescope are stored at the CNAF (Centro Nazionale Analisi Fotogrammi - National Frame Analysis Center) center in Bologna and are available for analysis.

Currently many of the telescopes installed in schools are not collecting data pending the replacement of the gas contained in the chambers with an equally efficient but less harmful gas for the environment.

At CERN was built also some Cosmic Boxes, portable devices that allow cosmic rays to be detected in any location. The Centro Fermi makes available these Cosmic Boxes through a competition in which schools can participate.

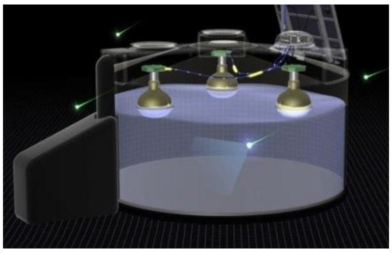
Cosmic rays’ detection

Detectors are instruments used to detect, track, and identify particles from cosmic rays, nuclear decay, and interaction processes in accelerators [6].
We list below some of these detectors and the methods they use to detect cosmic rays.

Track Detectors

Track detectors are made of materials that respond to charged cosmic ray particles.
When a charged particle passes through the detector, it leaves a trace by ionizing the atoms in the material. Analysis of these tracks helps determine type, energy, and direction of the incoming particles.

Cherenkov detectors

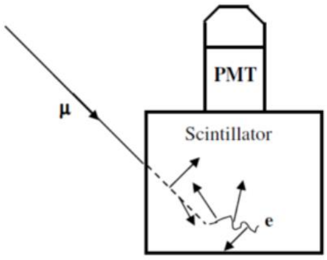


Cherenkov detectors rely on the Cherenkov effect, which occurs when a charged particle travels faster than the speed of light in a particular medium.

This effect causes the emission of Cherenkov light. By detecting and measuring this emitted light, Cherenkov detectors provide information about the nature and energy of the particles.

Fig 2: Cherenkov detectors. (https://doi.org/10.1016/j.nima.2020.163678)

Scintillation detectors



Scintillation detectors consist of materials that emit light (scintillation) when high-energy charged particles pass through them. The emitted light is detected by photodiodes or photomultipliers that convert it into detectable electrical signals.

Analysis of these signals provides information about the energy and type of particles detected. [7]

Fig. 3. Scintillation detector (https://physicsopenlab.org/2016/01/04/scintillation-muons-detector)

Gamma ray detectors

High-energy gamma rays can be detected with scintillators or solid-state detectors that are sensitive to this radiation. When a gamma ray interacts with the detector material, it produces detectable signals such as scintillation or ionization. These signals can be recorded and analysed to determine the energy and other properties of the gamma rays.

Applications of Cosmic Ray Detection

The detection of cosmic rays has several important applications in scientific research:

- understand the origin and nature of cosmic rays, which provides valuable clues to the formation of stars, galaxies, and high-energy cosmic objects;
- identify the different types of cosmic particles, distinguishing between protons, electrons, positrons, and atomic nuclei;
- provide information on the spectral distribution and the amount of energy transferred by cosmic particles;
- observe the universe using cosmic rays to study high-energy astrophysical phenomena such as gamma-ray bursts, supernovae, black holes, and active galaxies;
- study the composition of cosmic rays to understand particle interactions in interstellar space and the properties of the early universe.

The EEE project Instruments

To detect primary cosmic rays, experiments must be deployed on orbiting satellites that can "capture" the cosmic rays. This method detects cosmic rays up to an energy that is not too high.

Cosmic rays with high energy are detected with experiments performed mainly on the Earth's surface.

The main detector (usually called “telescope”) used in the EEE project, consists of three superimposed Multigap Resistive Plate Chamber (MRPC) that detect cosmic rays through the ionization of the gas contained in them.

Measurements include the length of the track, the time of flight, and the number of tracks detected. The measurement station also provides all the environmental parameters of the place where the detector is located, as these can influence the data and, in some cases, cause the instrument to malfunction, for example in the case of very high temperature.

The EEE project uses also a portable detector, the Cosmic Box, consisting in two parallel plates of scintillator material coupled with SIPM (Silicon Photo Multipliers) photosensor. This detector counts the cosmic rays that pass through its plates.

How the Cosmic Box works

The Cosmic Box consists of two plates (size 15 cm x 15 cm x 1 cm) of scintillator material placed parallel to each other at about 30 cm. When a charged particle passes through one of the plates it releases some of its energy which is converted into photons by the scintillator material. These photons are detected by a photosensor and converted into an electrical signal. To make this possible, the structure of the detector is designed to direct all generated photons to the photosensor. To avoid capturing spurious events, the Cosmic Box can record the data only when a charged particle is captured by both scintillators: when the Cosmic Box works in this mode, it can only select reliable events within a certain solid angle and show the obtained data on its display. The larger the distance between the two scintillators, the smaller the number of particles detected by the Cosmic Box, since they are contained within a smaller solid angle. The intrinsic efficiency of the detector (the probability of detecting a particle) is close to 100% for strongly charged particles. Instead, only a small fraction of charged particles produce too little light to be detected by scintillators. [8]

Measurements at “Mercati di Traiano”

The "Mercati di Traiano" is a complex of buildings built mainly during the reign of Trajan (98-117 CE) in the Roman Fora on the Quirinal Hill. The complex was part of Trajan's Forum and served mainly as commercial and residential buildings.

Fig.4. Trajan’s Market.

A small passage, the Via Biberatica, divides the entire complex into two parts. The lower part consists of a three-story hemicycle. On the first floor there are initially small niches that open onto a street. In Roman times, they served as small stores where merchants could display their wares. These shallow rooms all have different depths because the builders had to construct them on the slopes of the Quirinal. The other two floors are accessible by stairs on the sides of the semicircle. The Via Biberatica separates this first commercial area from the commercial and residential area of the entire complex. Archaeologists believe that the buildings on the sides of the passage were "insulae", that is, a residential building that had a "taberna" (a place for commercial activities) on the first floor.

The entire complex was built using the "opus latericium" construction technique, which consisted of building a concrete structure and covering it with tiles. In this way, the builders and the architect (probably Apollodorus of Damascus) were able to fill every available space on the slope.

Trajan's markets were probably built for commercial purposes, as Emperor Trajan wanted to avoid a shortage of food. Therefore, the "tabernae" and alcoves served to supply the Romans with goods. However, historians doubt the actual purpose of the markets and believe that they also served as places for administrative activities.

Over the years, the complex has undergone various changes. In the Middle Ages, noble families began to build defensive towers and elements next to it. In the 16th century it was transformed into a monastery and then into barracks. Finally, in the 20th century it was recognised as an archaeological site and today it is part of the Museum of the Imperial Forums. [9] [10]

Cosmic ray measurements into the “Mercati di Traiano”

The collection of data on the number of cosmic rays was done by five series of measurements.
The data of series 0 and series 1 were collected on the first floor of the archaeological site: series 0 in the open air and series 1 in one of the niches on the first floor. Series 2 and 3 data were collected on the second floor: series 2 partially outdoors in one of the openings of the building, and series 3 by placing the Cosmic Box in one of the rooms on the second floor. The data of series 4 were collected outdoors, on the roof of the monumental complex.
Tab. 1 shows the counts recorded every two minutes on the various floor of the building and the environmental parameters (pressure P, temperature T and relative humidity U) related with each series.

Time	**Counts**				
(minutes)	**Series 0** Ground floor. Outdoors. P=760 mmHg (± 1 mmHg) T=20°C **(± 1°C)** U= 70% **(± 1%)**	**Series 1** Ground floor. Indoors. P=760 mmHg, (± 1 mmHg), T=20°C (**± 1**°C) U=70% (**± 1**%)	**Series 2** First Floor. Outdoors. P=759 mmHg (± 1 mmHg) T=19°C (**± 1**°C) U=70% (**± 1**%)	**Series 3** First Floor. Indoors. P=758 mmHg (± 1 mmHg) T=18°C (**± 1**°C) U=72% (**± 1**%)	**Series 4** Second floor. Outdoors. P=757 mmHg (± 1 mmHg), , T=18°C (**± 1**°C) U=78% (**± 1**%)
(±0,02 min)	(±1 count)	(±1 count)	(±1 count)	(±1count)	(±1 count)
2	1	7	7	6	3
4	5	11	13	11	7
6	9	19	17	12	14
8	13	23	20	12	18
10	15	33	26	13	21
12	19	46	29	13	27
14	21	59	34	16	40
16	25	72	37	21	48
18	26	81	39	26	58
20	31	85	40	34	63

Tab. 1. Measurements performed on March 9th, 2023

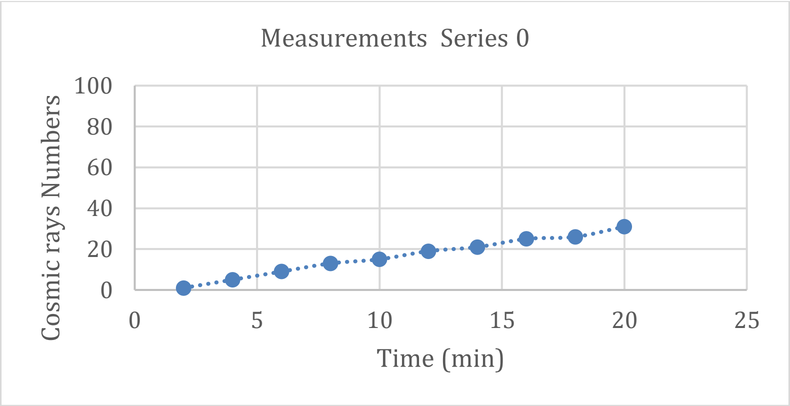


Fig. 5. Series 0. Ground floor. Outdoor

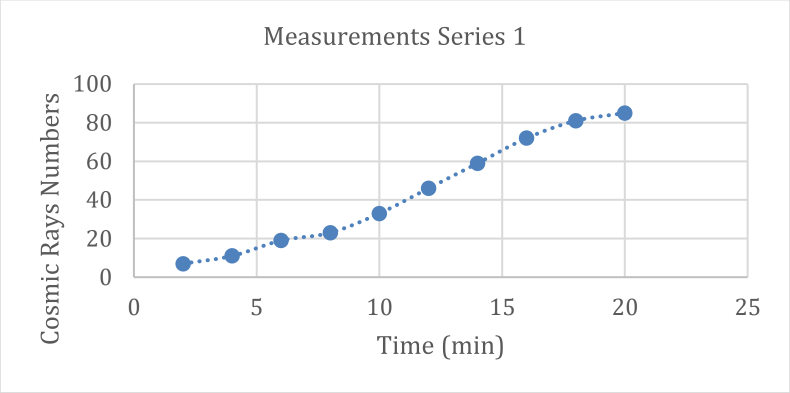


Fig. 6. Series 1.   Ground floor. Indoor

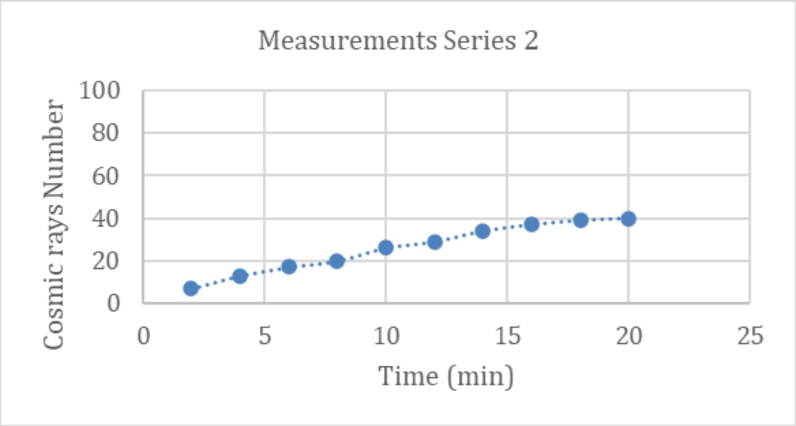


Fig. 7. Series 2. First Floor. Outdoor

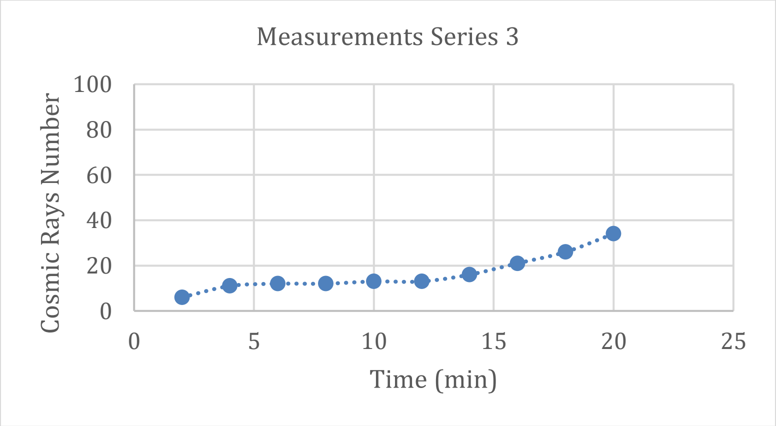


Fig. 8. Series 3. First Floor Indoor

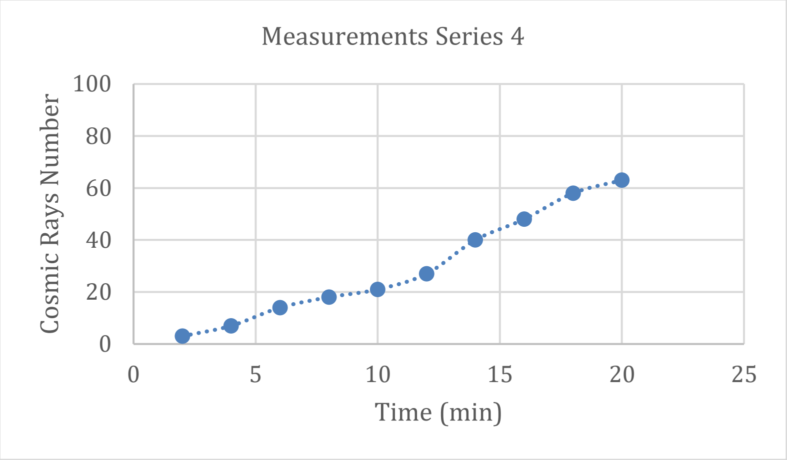


Fig. 9. Series 4. Second floor. Outdoor

The graphs in figures 5, 6, 7, 8 and 9 show that the number of cosmic rays is proportional to time, with a linear proportionality. In graph 1, the maximum value of the y-axis is 31. This value is the maximum number of cosmic rays detected in the open air, on the first floor. On the other hand, the maximum value of graph 2 (which represents the number of cosmic rays detected indoors, on the first floor) is 85. This result was not expected, since it was assumed that the maximum value of rays reaching the ground outdoors would be greater than the maximum value of rays detected indoors. The same can be seen in Fig. 7 and Fig. 8, which show the number of rays detected outdoors and indoors, respectively, on the first floor of the market.

Now it is important to understand the cause of these results. Possible reason for the results can be the effect of the ceiling of the room of the markets: the ancient Roman monuments are made of tuff, a radioactive rock (it emits radon). The vault, under which the box was located, was composed of tuff: this shields the rays and increases the count per minute and the maximum value of the detected rays.

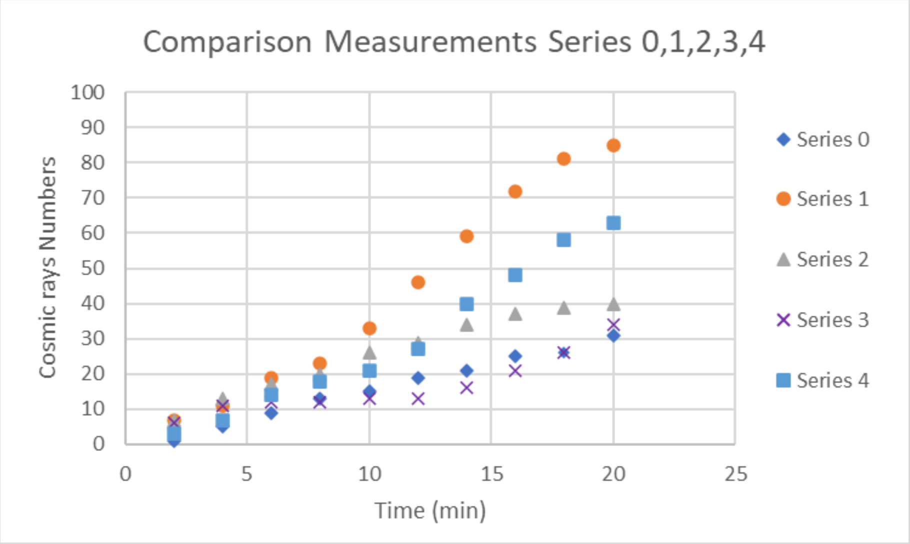


Fig. 10. Comparison Measurements Series 0,1,2,3,4.

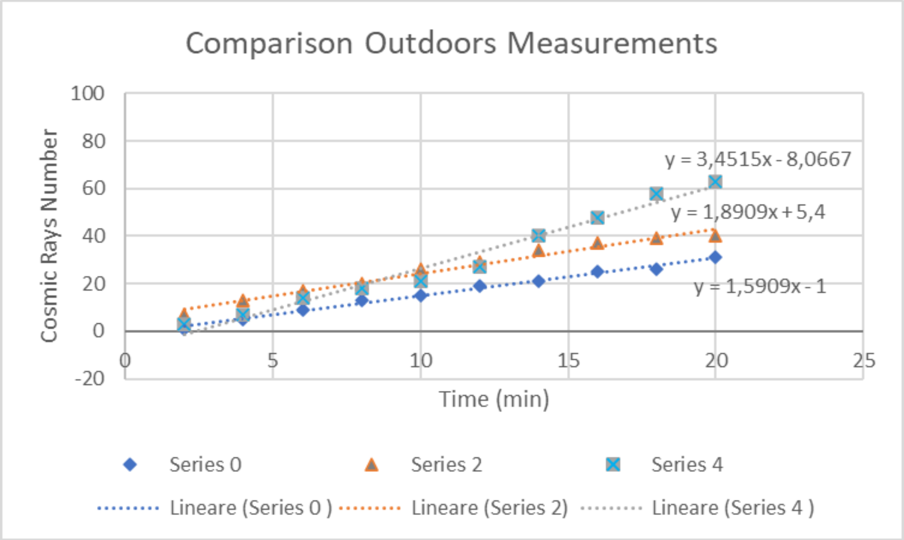


Fig. 11. Comparison Outdoor Measurements:

series 0 – ground floor; series 2 – first floor; series 4 – second floor

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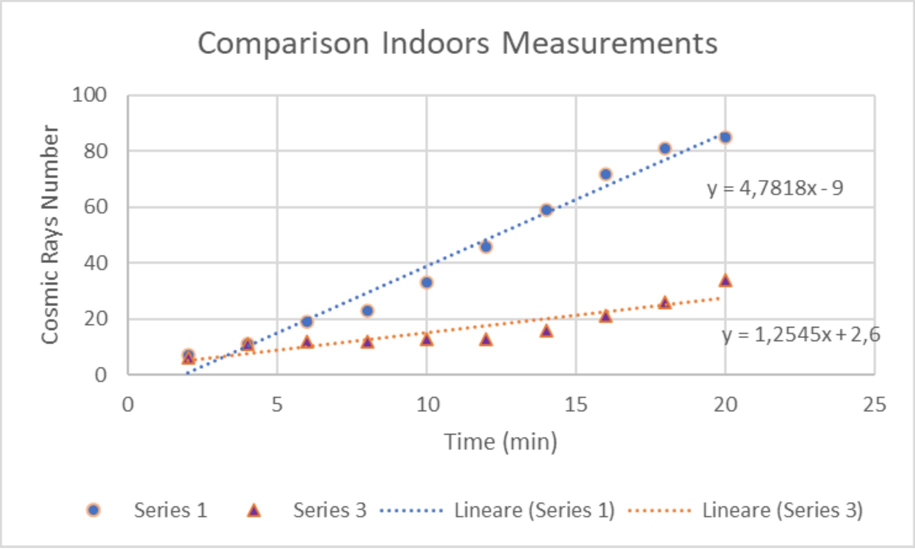

Fig. 12. Comparison Indoor Measurements:

series 1 – ground floor; series 3 – first floor

All the graphs (10, 11, 12) show a constant increase in counts/min along with the altitude.
In Fig. 11 and Fig. 12 is shown also the linear fit of the data.

The graph 12 shows an unexpected number of cosmic rays revealed by the Cosmic Box on the ground floor (series 1) of the building inside a niche. As already noted, this may be due to the radiation emitted by the tuffaceous rocks of the archaeological site.

Conclusions

The measurement campaign confirms the theory about the linear proportionality between the number of cosmic rays and height.
The measurements are carried out both outdoors and under the arch of the "Mercati di Traiano".
For each level of the building, both outdoors and indoors measurements are recorded.
The outdoor measurements (Fig. 11) confirm the usual increase of cosmic rays with increasing altitude.
Nevertheless, a greater number of cosmic rays are detected in the indoor measurements than in the outdoor ones (Fig. 6) at the first level of the building.
We suspect that this is probably due to the material, since the ancient Roman monuments are made of tuff, a radioactive rock (it emits radon) and the vault, under which the box was located, was composed of tuff. In the second indoor measurements at the second level of the building (Fig. 8), the increase in the number of rays is not as relevant as in the first level of the building. It is probably due to the material from which the room was built that apparently shields the rays.

References and sitography

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