UNIVERSITÀ DEGLI STUDI DI SALERNO
Dipartimento di Matematica

CRIS 2022
12th Cosmic Ray International Seminar
Naples, Italy, September 12 -16, 2022

INFN NAPOLI
Istituto Nazionale di Fisica Nucleare
Sezione di Napoli

INTERDISCIPLINARY SCIENTIFIC STUDY RESEARCH WITH TECHNOLOGY-ENHANCED LEARNING

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In the laboratory

students work as physics researchers

within the project

“Mathematical High School”

that aims to develop transdisciplinary themes where maths is the cultural glue between the various fields of knowledge

The activities have been developed by

Department of Mathematics of the University of Salerno (Italy)

in collaboration with

INFN - Sezione di Napoli (Italy)

INTRODUCTION

Relating to the Italian Educational System, the guidelines of the Italian Scientific High Schools, specifying learning objectives of physics, state:

"*The experimental dimension could be further deepened with activities not only in the computer school laboratories but also at University laboratories and research institutions by joining projects. In this context, the student will be able to examine issues of interest, approaching at more recent discoveries of Physics (for example in the field of Astrophysics and Cosmology, or in particular physics)*".

S.T.E.M. CURRICULUM

The S.T.E.M. curriculum incorporates the "four C's" of 21st-century skills:

Creativity, Critical Thinking, Collaboration, Communication

- Students work together to
  - create innovative solutions to real-world problems
  - communicate their solutions with others
  - discover the most effective and efficient ways to access and manage the world of digital information using appropriate technology tools

NATIONAL PLAN FOR DIGITAL SCHOOL

- In Italy, the National Plan For Digital School (PNSD) states
  - digital technologies intervene to support all dimensions of transversal skills
  - they also fit vertically, as part of the literacy of our time and fundamental skills for a full, active and informed citizenship as anticipated by the Recommendation of the European Parliament and the Council of Europe
  - emphasized by the 21st Century Skills (Skills for the 21st Century) promoted by the "World Economic Forum"

THE MATHEMATICAL HIGH SCHOOL PROJECT

Liceo Matematico

The Mathematical High School (MHS) is

- an experimental didactic research-project,
- promoted by the Department of Mathematics of Salerno (Italy) and currently active in over 160 institutes in the whole Italy
- developed in scientific high schools performing integrative interdisciplinary activities in laboratory mode with the collaboration of universities and research institutes.
- dedicated in extra-curricular hours
- focused on the use of the most recent technologies to deal with the rapidly evolving world of work

The "Astroparticles" PROJECT, a path in MHS

- Among the activities proposed to the third year high school students participating in the project, an interdisciplinary path in the scientific field to **study particle physics through the use of highly technological and specialized scientific instruments**, has been developed in collaboration between the mathematics department of the University of Salerno and the INFN – Napoli Unit.

The "Astroparticles" PROJECT, a path in MHS

- The MHS students experimented
  - the activity of astroparticle physics researchers with the team cooperation
  - from the catch of the data to the final relations they have been carried out in groups with the learning-by-doing methodological approach.
- The INFN researcher activities are based on the data collected by the **Cosmic Ray Cube** (CRC), a cosmic muon detector
  - **developed at LNGS** (Laboratori Nazionali del Gran Sasso)
  - **used in the OCRA** (Outreach Cosmic Ray Activities) INFN program.

THE PROJECT

The didactic path has been developed in four meetings of 2.5 hours each for a total of 10 hours. During the lessons students participated in some introductory seminars on astroparticle physics. Graphic animations were used to better explain topics that may seem unreal to a young student.

THE PROJECT

- Thanks to a dedicated software, they collected data, processed and analyzed them as researchers do
- the activity is designed for high school third grade students and has been presented to various classes over the past three school years.
- The course has been designed to be carried out in person but, due to the pandemic lockdown, in some classes the activity took place remotely

METHODOLOGY

- The constructivist theory of learning that belongs to Vygotsky represents the methodological approach that guided the construction of the various experimental paths elaborated by the INFN researchers
- The artefacts play the role of semiotic mediators of knowledge as transmitters of knowledge in teaching-learning processes in which trainers, researchers, teachers assume the role of cultural mediators.

THE ACTIVITIES

The students collected cosmic muons with the cosmic ray cube, a portable muon detector designed by the Gran Sasso laboratories (Italy), analyzed the data and compiled forms prepared by the researchers.

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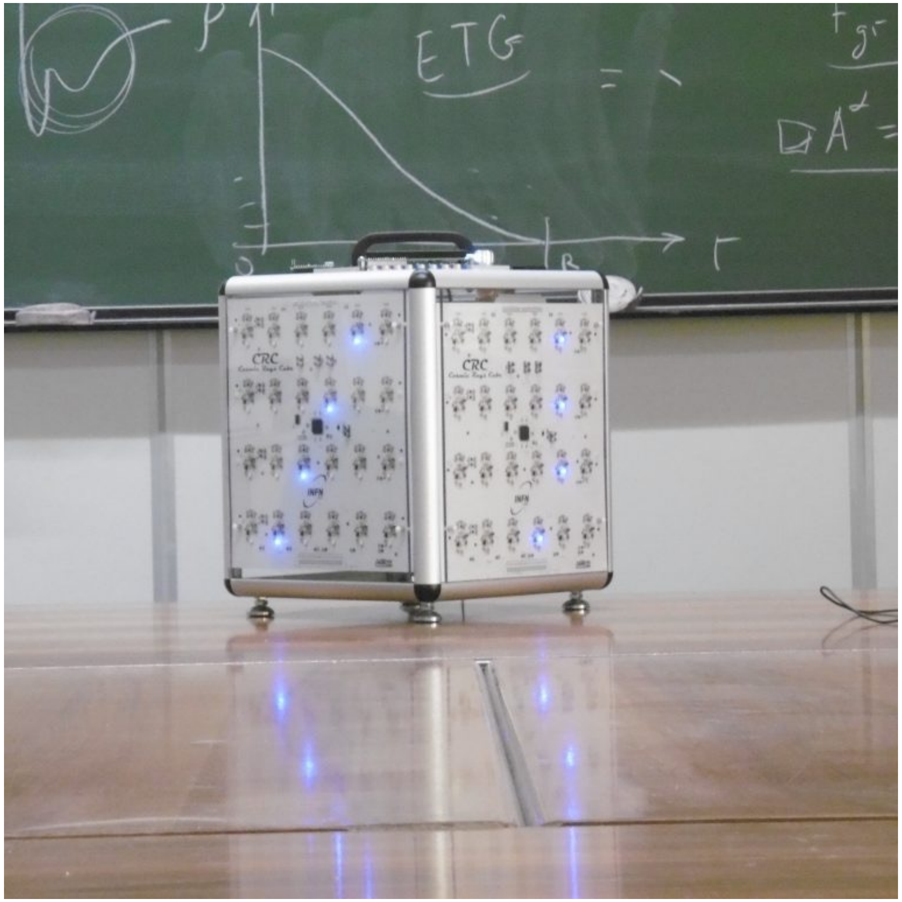
The Cosmic Ray Cube (CRC): a portable detector for cosmic muons



The experimental setup consists of a cosmic-ray detector, the CRC, and a pc supporting an application which allows user to record the measurements of the telescope.

The CRC is composed by 4 layers of plastic scintillator.

Each layer is divided in two sub-layers for a **two-dimensional reading of the particle trajectory**.

Each sub-layer consists of 6 scintillator bars read by a Silicon Photomultiplier (SiPM).

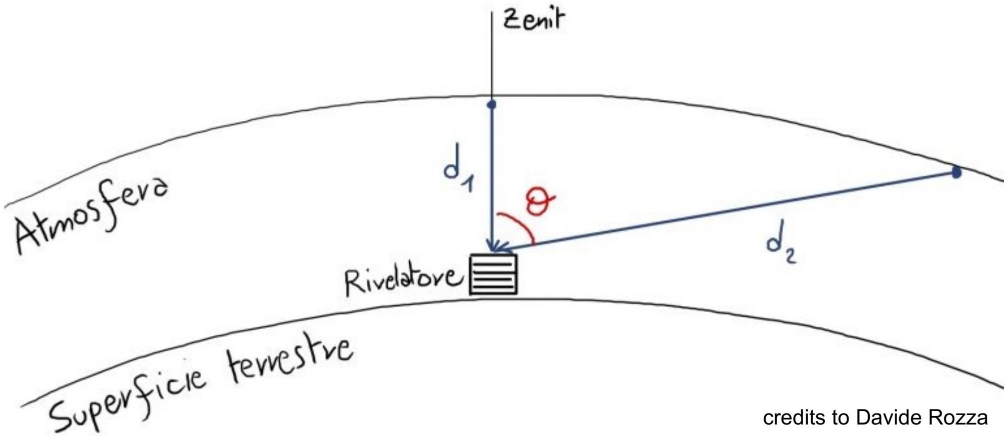
The SiPM transforms the collected light into an electric impulse that allows the lighting of a LED connected to it.

The bright LEDs show the projection of the particle trajectory on the two faces of the telescope

THE MUON RATE:
CRC used as counter

The rate of cosmic particles reaches a maximum value at zenith, and continually decreases at increasing zenith angles. At 90° the rate is minimal.

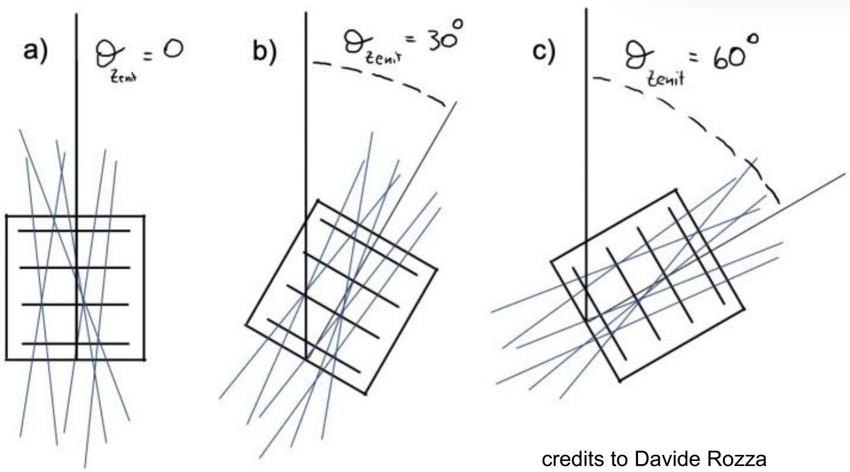
The main effect to describe this is the **muon path through the atmosphere**:
with a larger angle of incidence, the distance from the place of origin of the muons in the atmosphere to the detector on the earth's surface is extended and the probability that muons reach the detector decreases.



credits to Davide Rozza

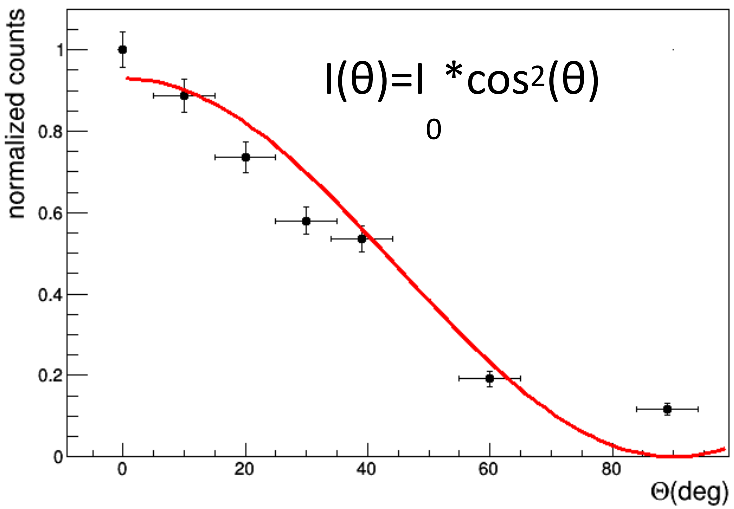
THE MUON RATE: CRC used as counter

- Students counted the number of particles that passed through the telescope and turned on at least on LED per layer in five minutes.
- They repeated the procedure by tilting the telescope at different angles, with steps of about 10 degrees.



credits to Davide Rozza

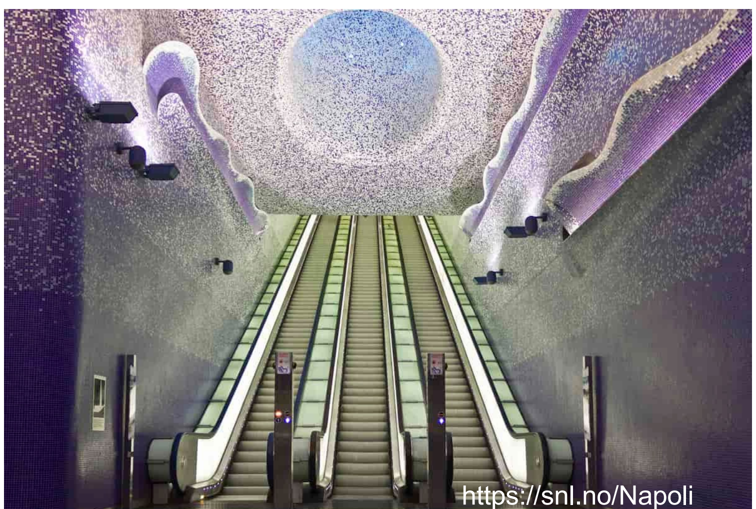
- Finally, **they plotted their experimental data (black dots) and compared them with the theoretical expectation (red line)**.



$I(\theta)=I_0 * \cos^2(\theta)$

THE TRACKER

The exercise to reconstruct the particle trajectory in 2D and 3D is performed on data collected by a telescope located at the "Toledo" metro station in Napoli. It has the same characteristics of the CRC, but more layers and horizontal bars. Trajectories can be imagined as a 10x10 matrix in zx and zy planes.

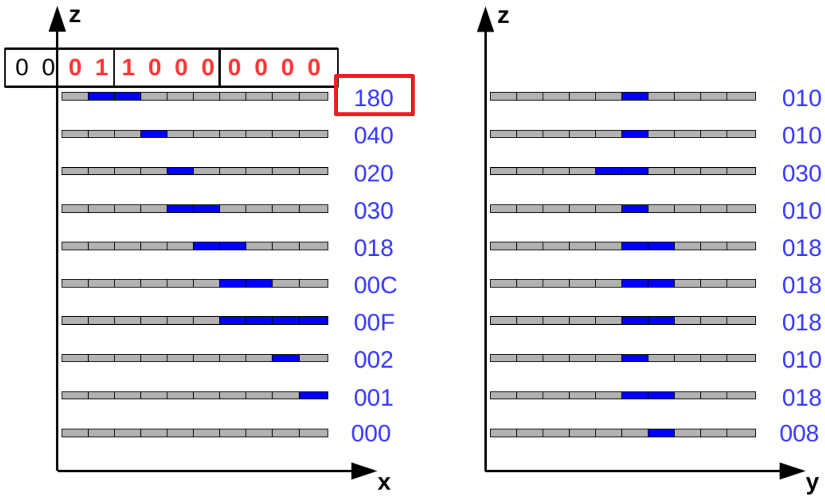


Information is saved in hexadecimal data, one for each plane.
Each hexadecimal number hides a 12x10 matrix with "0", indicating LEDs that are off, and "1" indicating bright LEDs. The first two columns don't contain physical information.

RECONSTRUCTION OF MUON TRAJECTORY in 2D and 3D

STF337
0000100200F00C018030020040180
008018010018018018010030010010

Hexadecimal format



Students write the **matrix** decoding hexadecimal numbers, and obtain the couples of experimental points from the matrix.

x	z
10	2
9	3
7	4
8	4
9	4
10	4
7	5
8	5
6	6
7	6
5	7
6	7
5	8
4	9
2	10
3	10

Couples of experimental points in the zx plane. We have 16 couples corresponding to the 16 bright LEDs.

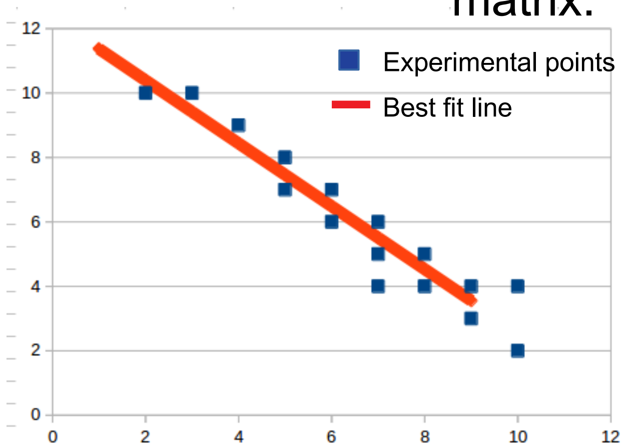
Least mean square formula

$$z = mx + q$$

$$m = \frac{\sum_i [x_i - M(x)][z_i - M(z)]}{\sum_i [x_i - M(x)]^2}$$

$$q = M(z) - m * M(x)$$

Where:
M(x) is the mean of x_i value
M(z) is the mean of z_i value



Using the least mean square formulas and excel as work tool, student find the best fit line and reconstruct the trajectory in each plane (2D reconstruction).

The last step is the reconstruction of the theta and phi angles that identify the 3D line/trajectory.

COGNITIVE TESTS

To evaluate the educational impact we submitted questionnaires divided into two parts:

- some questions to investigate what it was the thought on the figure of the physicist and of the research,
- a second part on specific questions concerning the cosmic rays

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QUESTIONNAIRE

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Enter a score from 1 (disagree) to 5 (strongly agree) for each of the following statements.

		School year 2019-2020		School year 2020-2021	
Question		Answer before the beginning of the activities (grade average)	Answer after the data collection (grade average)	Answer before the beginning of the activities (grade average)	Answer after the data collection (grade average)
1	I have some idea of what a physicist does in his research	3,50	3,95	3,03	4,09
2	I have some idea what the aims of physics research are	3,60	3,95	3,34	4,02
3	I think the module is useful for my studies.	3,85	3,58	3,94	3,95
4	I think I will learn a lot of new things.	4,35	4,47	4,47	4,19
5	I think the module will be useful for me to better understand the world around me and face everyday problems differently			3,48	3,66

QUESTIONNAIRE (2nd part):

- In the second part of the questionnaire open questions were proposed to the students
- Some of the questions to outline the type of requests:
  - What are cosmic rays and what are the components of an extensive air shower?
  - What are muons and how are they measured?
  - Muons live 2.2 μs (2.2 10^{-6} s), travel at a speed close to that of light and have to travel about 15 km across the atmosphere to reach Earth. How can they reach us?
  - Why does the ground flux of cosmic muons decreases as the zenith angle, the angle formed by the vertical and the particle trajectory, increases?
  - How does muography work? Remembering that muons can travel through large thicknesses of materials before being absorbed, do you think it is possible, thanks to cosmic muons, to X-ray large structures? Try to give some examples.

CONCLUSIONS

- The collaboration between teachers and researchers allowed students
  - To observe the historical contextualization of the phenomena studied, the theoretical physical description of the collected data
  - To discover how distant the figure of the contemporary scientific researcher is from the model of scientist who is usually transmitted in books
  - Students found the course effective and exciting because they were asked to search for answers and analyse "raw" data thanks to the most innovative tools offered by new technologies
  - to understand that the research world proceeds and progresses thanks to the interconnection of the specialized knowledge of many reference figures and thanks to the technology that allows the exploration and verification of hypotheses and models that are theoretically structured.

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thank you for your attention!

For any question

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