The Extreme Energy Events project

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Cosmic ray physics experiment with double goal:
Educational / outreach and scientific research
• hands-on activity for high-school students with the aim to stimulate their interest in science through their involvement in all stages of the project (detector construction, installation, comissioning, data-taking, analysis)
• research in cosmic ray physics

A collaboration of
• Centro Fermi – Roma Museo Storico della Fisica e Centro Studi e Ricerche "Enrico Fermi"
• INFN Istituto Nazionale di Fisica Nucleare
• MIUR Ministero dell’ Istruzione, dell’ Università e della Ricerca
• CERN European Organization for Nuclear Research
In 1909 Theodor Wulf measured, using an electrometer, higher level of radiation at the top of the Eiffel Tower than at its base.

Victor Hess, using balloons, measured in 1912 atmospheric ionisation as a function of altitude. As he ascended to 5300 metres, he measured the rate of ionization in the atmosphere and found that it increased to some three times that at sea level. He concluded that penetrating radiation was entering the atmosphere from above. He had discovered cosmic rays.
What are cosmic rays

Very energetic charged particles coming from outer space that continually bombard the earth

- Protons (hydrogen nuclei) 89%
- Helium nuclei 10%
- Heavier nuclei 1%

When they collide with atoms in the earth's upper atmosphere, they create a shower of lower energy secondary particles, mainly pions. Pions swiftly decay emitting muons, which travel through the atmosphere and penetrate below ground.

A hundred of these secondary particles pass through our bodies every second.

Energies of primary cosmic rays

- from 1 GeV (rate : 10 000 / m²s)
- up to 10⁸ TeV (rate : < 1 /km²century )

Very high energy cosmic rays generate huge showers of up to 10 billion secondaries spreading over areas of 20 km² at the surface of the earth.
$N = 10^6$

- $N(e) = 18\%$
- $N(\gamma) = 18\%$
- $N(p, n, \pi) = 0.3\%$
- $N(\mu) = 1.7\%$
The project
Some history..

Launch event: 3 May 2004
Webcast from CERN
Professor A. Zichichi
Minister L. Moratti
watched by many Italian schools

A. ZICHICHI, Progetto "La Scienza nelle Scuole"
EEE – Extreme Energy Events
Società Italiana di Fisica (SIF), Bologna
Look for extended air showers and extreme energy events

By detecting the muon component of the shower

Simulation of a shower induced by a $10^{17}$eV proton
At ground level 1 million muons arrive, over an area with radius at least 2 km.
• Place telescopes all over Italy in Italian High Schools  
• Look for coincidences between telescopes

Key ingredient: define direction of muon - so that we can point back to interaction point in atmosphere  
check that muons belong to same shower and also get direction of incoming particle
An array of muon telescopes

At present

~50 in Italian High Schools

They are mostly distributed in clusters in the whole Italian territory

+ 2 telescopes at CERN
+ 4 in INFN Units or Universities

~45 schools on the waiting list
The experimental apparatus
The detector: 3 Multigap Resistive Plate Chambers (MRPC)

- 6 gas gaps of 300 microns each
- Dimensions: 82 cm x 180 cm

➢ Requirements: reliable (long-term); easy to use; not expensive
➢ Design based on the MRPCs of the ALICE Time Of Flight (TOF)
The ALICE Time Of Flight detector

Multigap Resistive Plate Chamber
10 gaps of 250 microns each

Cylindrical array of 150 m² r=3.7m
1600 MRPCs in 18 Supermodules

System time resolution $\sigma = 70$-80 ps

**Correlation $\beta = v/c$ versus momentum**
**as observed by TOF in Pb-Pb collisions.**
**Particle species are clearly separated in the intermediate $p_t$ range**
The EEE MRPC

Operated with a mixture of 98% $\text{C}_2\text{H}_2\text{F}_4 - 2% \text{SF}_6$

Efficiency (in dedicated beam tests)

Time resolution (in dedicated beam tests)

Performance of a six gap MRPC built for large area coverage

Signal readout

- 24 strips read out at both ends
- Time difference: position of hit along the strip
- Anode & cathode readout plane: differential signal

Adhesive copper tape on vetronite sheet
Strip width: 2.5 cm; Distance between strips: 0.7 cm

Space resolution in x and y: ~ 1 cm

2 FEAs per MRPC

FEA card
- 3 NINO asics / 24 channels
- Amplification
- Discrimination
- Stretching of pulse
- OR of 24 signals

27.3.2023
Electronics

- TDC
- TDC
- VME Bridge
- Trigger unit
- GPS Unit
- 144 channels TDC
- VME crate
- Data Acquisition and monitoring based on Labview

Hytec (or Spectracom) GPS to generate time stamps and synchronize stations at different location.

CAEN V1190A
CAEN V1190B
CAEN V1718

Trigger card
6-fold coincidence

USB connection to PC
VME Bridge
In addition

Weather station to monitor
• temperature
• pressure
read out by the DAQ
The HV system

Working voltage for MRPCs: 18 - 20 kV
- DC-DC converters inside small boxes
- EMCO Q series converters providing an output voltage up to ±10 kV for 0-5 V input
The students’ involvement
Phase I. Construction of muon detectors (MRPCs)

• Done by high-school students and teachers at CERN supervised by researchers*
• Each school sends 5-10 students accompanied by 1-2 teachers
• During their week-long stay at CERN they build 3 chambers

*Special agreement with CERN to allow children <18-years old to work in CERN labs

- 2005  7 schools (pilot)
- 2006  14 schools
- 2009  10 schools
- 2012  3 schools
- 2014  6 schools
- 2015  6 schools
- 2017  6 schools
- 2019  4 schools

Total: 56 schools 300-400 students 60-90 teachers
preparation of readout copper strips

preparation of honeycomb panels
Fishing-line spacers

27.3.2023
Cleaning glass panels
preparation of signal cables
Soldering signal cables
Closing the gas box with the MRPC
Chambers under gas flow to test for leaks

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Chambers are shipped to Italy
Phase II: assembling the muon telescope

Gas system

readout and DAQ

Chamber arrival

The telescope assembled

D. Hatzifotiadou: The EEE Project
27.3.2023
Phase III. Data-taking and monitoring

Check DAQ is ON

Check GAS flow

(Empty bottle?)

Check chamber hit distributions
Data-taking

Pilot run: 27 October-14 November 2014 (23 – half of the EEE telescopes)
Run 1: February 2015 – April 2015 (two third, 35 of the EEE telescopes)
Run 2: November 2015 - May 2016 (almost all EEE telescopes)
Run 3: October 2016 - May 2017 (almost all EEE telescopes)
Run 4: October 2017 - May 2018 (almost all EEE telescopes)
Run 5: October 2018 - May 2019 (almost all EEE telescopes)
Run 6: October 2019 – stopped due to COVID pandemic
~95 billion tracks collected up to now
A complex software architecture has been set-up to reconstruct the data and provide quasi-online (few hours) histograms on the web for monitoring purposes.
Phase IV: students’ participation in coordinated run

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**Fill the e-logbook**
Check the CNAF on-line monitoring system
monthly run coordination video-conferences where the students present the status of their telescope / data-taking / analysis

prof. R. Zingoni liceo scientifico F. d’Assis

27.3.2023
How to measure the amount of gas in a bottle by means of sound frequency

Liceo F. e M. Campana (Osimo)
Both measurements were published in the *Giornale di Fisica* with students’ signature.
EEE at International Cosmic Day 2017
47 Schools, 550 students

Liceo Galvani (BO):
data from their telescope
EEE outside Italy

- Moscow Chemical Lyceum
- Student exchanges between schools: Liceo Staffa Trinitapoli (Bari) and Moscow Chemical Lyceum

French HSSIP 2017, Swedish HSSIP 2018, etc..

- Themistokli Germanjy Lyceum (Korce, Albania)
- Istituto de Ciencias Nucleares UNAM (Mexico)
- Oslo University (Oslo)
Some results

- Search for extended air showers
  Coincidences between muon telescopes
- Variation of muon flux in single EEE stations
  Observation of Forbusch decreases
- Study of upward-going particles
  electrons from $\mu$-decay
First detection of extensive air showers with the EEE experiment

D. Hatzifotiadou

The EEE project
At L’Aquila, closest stations of the experiment

Angular correlations between “coincidences”

7.6 events/hour
Signal/Noise = 2

Angular cut (requiring quasi parallelism) improves S/N
1.6 events/hour
Signal/Noise = 18

Time difference between events at the two stations
First coincidences detected

Single track in one school + multiple tracks in the other school
3.6 events / hour
Signal / Noise = 26.4

Multiple tracks in both schools
0.8 events / hour
Signal / Noise = 76
Coincidences up to 2012...

Number of coincidences per day, as measured by different telescope pairs of the EEE network, versus the relative distance between the two telescopes.

Results consistent with Corsika and Cosmos Monte Carlo simulations.

Few months to observe coincidences for distances > 1 km.

Corsika Monte Carlo simulations.
... coincidences during Run-1

Coincidences were observed for several distances between telescopes: 15 m, 100 m, 200 m, 500 m, 1200 m.

Increasing the distance between telescopes the energy of the primary observed increases as well.
Coincidences at Cagliari

- Telescopes distance = 520 m
- Days analyzed = 125

Preliminary
Pilot Run + Run-1

Coincidences at Savona

- Telescopes distance = 1180 m
- Days analyzed = 120

Preliminary
Pilot Run + Run-1
Forbush decrease 2011

- rapid variations of the cosmic rays flux over the course of a few hours associated to solar phenomena as CME (Coronary Mass Emission) and solar flares
- Decrease in muon flux reaching a minimum within hours
- Recovery lasts a few days
- comparison with Oulu neutron monitor station
Solar flares: explosions on the sun, related to storage of energy in twisted magnetic fields -> burst of EM radiation (from radio waves to gamma rays)

Classification: according to intensity in wavelength range 0.1-0.8 nm

Solar flare, of category X2, followed by an important Coronary Mass Emission (CME) Observable on earth a few days after the event

This kind of flares are constantly monitored since they may have relevant consequences on Earth
Forbush decrease 2012

Solar flare on March 6 2012 of category X5.4

- Neutron monitors in Oulu and Rome
- Liceo Gagnazzi – Altamura
- Liceo Galvani, Liceo Fermi – Bologna
- INFN Bologna
- Department of Physics – Catania
Upward-going events

Time-Of-Flight (TOF) :
Time Bottom Chamber - Time Top Chamber*

TOF<0 : upward-going particle

Muons from (atmospheric) neutrino interactions with the earth ?

Too many upward-going events observed

* intriguing!

* Top and Bottom chambers are read out with the same TDC : same clock used
Upward-going events

About 1 event every 1000 observed goes in an upward direction. Some of them identified as electrons from muon decays (in the floor or in the bottom chamber), looking at their Time Difference with respect to the Previous (TDP) events.

Event display (in the two projections)  Tagged downward $\mu$ + upgoing electron
Identify electrons from muon decays (in the floor or in the bottom chamber): look at Time Difference with respect to the Previous (TDP) events versus velocity

\[ \beta > 0 \text{ downward-going} \]
\[ \beta < 0 \text{ upward-going} \]

Correlate TDP with velocity of previous particle: electrons come from decays of (slow) muons with \( 0.5 < \beta < 0.8 \)

For \( \beta \sim 0.65 \) range of muons in Al / concrete is 2-3 cm
Electrons from \( \mu \)-decay, \( E=50 \text{ MeV} \), range in Al 7 cm
Muon decay

low energy electrons from muon decay are a robust explanation for upward-going particles
The Project Extreme Energy Events - Science inside Schools (EEE), is a special research activity about the origin of cosmic rays, performed in collaboration with CERN, INFN and MIUR and carried out with the essential contribution of students and teachers of high schools.

Each of the participating institutes hosts a "telescope" made of the most advanced particle detectors (Multi-gap Resistive Plate Chambers, MRPC). EEE telescopes are put in coincidence using GPS, with the goal to detect cosmic muons and extensive showers (as large as a small town), produced by primary cosmic rays of the highest energy. Data from all telescopes are sent to CNAF-INFN, in Bologna, to allow track reconstruction so that all relevant information can be stored in a database to be later available for analysis.

Students are involved in the fundamental task to build the chambers, starting from simple materials to arrive to sophisticated high precision detectors. This task is accomplished at CERN, one of the most important particle physics laboratories in the world, which is made open to students specifically for this project. Students have also the task to control the correct operation of the telescope installed at their school.

Presently 52 high schools distributed across Italy host a telescope. Other 53 institutes participate to the project by analyzing data. More than 60 billion tracks have been collected in the past years and are presently studied by students and professional researchers performing interesting analysis, some of which have already been published in various international scientific journals.

Download allegati: Extreme Energy Events - La Scienza nelle Scuole di A. Zichichi (versione 1.0)
After a ~ 2 years interruption due to the COVID pandemic EEE is restarting slowly

Problem : current gas mixture used has a Global Warming Potential GWP = 1880

Study of alternative, eco-friendly gas mixtures
Candidates : \( \text{C}_2\text{H}_3\text{F}_4 - \text{CO}2 \) mixtures ; \( \text{C}_3\text{H}_2\text{F}_4 - \text{He} \) mixtures

Extensive studies of performance at CERN, Bologna, Pisa, Cosenza

Some pilot school started data-taking with \( \text{C}_2\text{H}_3\text{F}_4 - \text{He} \) mixtures

Workshop in Erice 20-23 November 2022
International Muon Week (IMW) is held annually each spring. In IMW, high school students and teachers conduct cosmic ray experiments, troubleshoot, interact, and ask questions. Later, participants are able to discuss data and ask further questions through follow up Zoom connections. There are three choices of experiments: Time of Flight, Cosmic Ray Flux, and Muon Lifetime. We encourage users who have access to the QuarkNet Cosmic Ray E-Lab to perform a Time of Flight study with students. This study allows students to make measurements of the speed of muons as they pass through the Cosmic Ray Muon Detector (CRMD).

Link: https://quarknet.org/content/international-muon-week
Astroparticle Physics

Astroparticle physics is a field of research that combines particle physics with astronomy and gives us spectacular insights into the universe. Using the smallest particles we know and developing new outstanding technologies, we can observe the objects and structures in our universe. These developments have brought us many new discoveries in the last decade. It has become clear that light - or more generally, electromagnetic waves - is not the only messenger of distant objects in the universe. Scientists around the globe are now able to use their telescopes to observe ultrahigh-energy cosmic rays, gamma rays, neutrinos, and even gravitational waves. The future is in combining all of these insights to understand the big picture.

In the projections around the measurement of cosmic rays, students can dive into the fascinating world of the exploration of the universe. They become familiar with scientific work using modern measurement and analysis methods. The contacts to scientist and research facilities as well as the gain of experience are meant to cater to the student interests and aid them in choosing their university major.

Projects

Finland

France

Germany

Italy

Poland

Japan

Russia

Spain

Sweden
International Cosmic Day

Discover Cosmic Rays

INTERNATIONAL COSMIC DAY

November 22 | 2022

Cosmic particles, these unnoticed particles that surround us all the time, are the focus of this day. Students, teachers and scientists get together to talk and learn about Cosmic Rays and answer questions like:

What are cosmic particles? Where do they come from? How can they be measured? And what can we learn from them?

If you want to know more about the secrets they bring with and to be part of this collaboration, get here more information:

https://cdc.desy.de
https://www.facebook.com/InternationalCosmicDay

Image Credit: DESY, Science Communication Lab
Thanks a lot for your attention

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