Advanced Nuclear Science and Technology Techniques Workshop

18-22 May 2026 NRF-iThemba LABS, Old Faure Road, Cape Town

Extreme Energy Events Project: A National Network of MRPC Muon Telescopes for Cosmic-Ray Physics and Science in Schools

M. Garbini for the E.E.E. Collaboration

Enrico Fermi Research Center

Born in 1999 in the wake of Enrico Fermi's legacy, the Institute has two primary goals:

- Promoting groundbreaking and impactful research that is rooted in physics and transcends disciplinary boundaries.
- Promoting scientific culture, with a particular focus on engaging new generations + modern Museum communicates Fermi's life and discoveries

Research @ CREF

Multidisciplinarity is at the basis of many projects

- Statistical Physics and complex systems in natural sciences
- Complexity for economic and technical developments
- Impact of AI in technology innovation
- Innovation and model for sustainability

Complexity

Applied Research

- Neuro science and neuro imaging
- Radio and hadrontherapy
- Physics for Cultural Heritage

- Photonic technology and AI
- Extreme Energy Events project : the science in schools
- Open problems in QM
- Kinematics and Dynamics of galaxies
- Nuclear Astrophysics with innovative sources

Basic Research

Museum

- The Regio Institute
- on the footsteps of Fermi
- the communication Office

Don’t miss us!!!


Fontana di Trevi
Museo Nazionale Romano, Palazzo...
Teatro dell'Opera di Roma
Via del Quirinale
Palazzo Esposizioni Roma
Via D'Azeglio
Via Cavour
Via Marsala
Pretoriano
Scuderie del Quirinale
Galleria Doria Pamphilj
Museo Storico della Fisica e Centro Studi e...
Via Milano
V. Gioberti
Roma Termini
Via Nazionale
Via del Boschetto
Via dei Serpenti
Monumento a Vittorio Emanuele II
Via Baccina
MONTI
Cavour
Regoli Pasticceria
Vittorio Emanuele
Via Cairoli
Via Giovan
Via dei Fori Imperiali
Via Conte Verde
ESQUILINO
Via Mecenate
Via Angelo Poliziano
Via Merulana
Viale Manzoni
V. Luigi Luzzatti
Foro Romano
Colosseo
Domus Aurea
Arco di Tito
Colosseo
Manzoni
Via di S. Teodoro
Via di S. Giovanni in Laterano
Via Labicana
Via Celio Vibenna
Via Ostilia
Via Tasso
Via Emanuele Filiberto
Colle Palatino
Parco Celio
Via dei SS. Quattro
Pontificio Santuario della Scala Santa
Basilic
Via Umberto Biancama

The E.E.E. Project (briefly)

The Extreme Energy Events Project is a Centro Fermi & INFN experiment with dual role

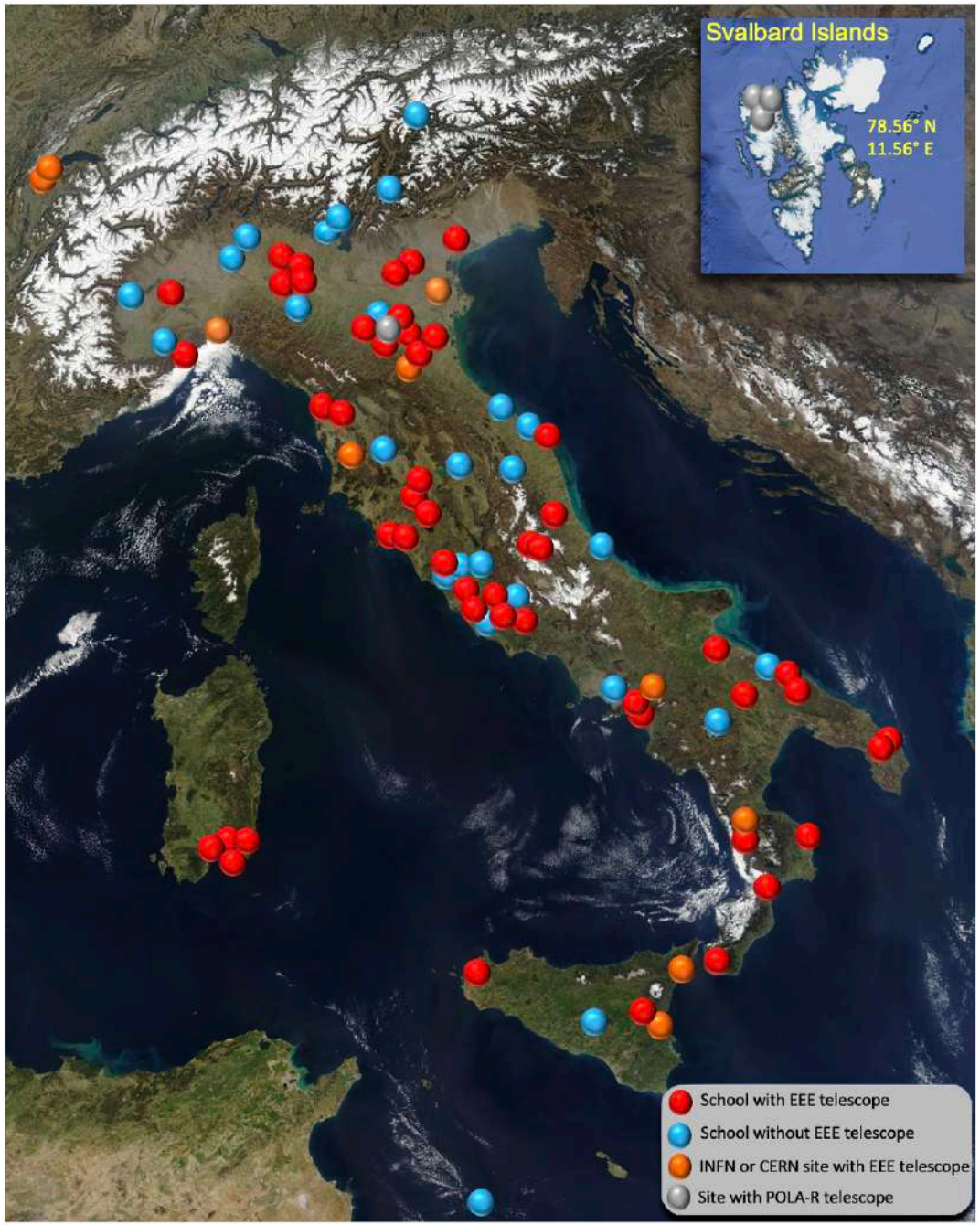
- Cosmic ray experiment: detection and study of cosmic rays at ground

- Scientific Education: involve high school students in all the phases of the experiment

Today EEE is a network of about
50
muon tracking telescopes installed inside Italian high schools, INFN laboratories, Centro Fermi and CERN.

Many other High Schools participating without telescopes

Hundreds of students working in the EEE experiment each year!



A bit of history

May 3rd, 2004: The EEE Project officially presented at CERN

Letizia Moratti (Ministry for Education and Research), Robert Aymar (CERN Director) and Antonino Zichichi meet at CERN

6A.1 – Progettazione di un telescopio con MRPC

L'apparato utilizzato per la rivelazione dei muoni cosmici deve soddisfare le seguenti condizioni:

i) deve poter coprire una grande superficie e di conseguenza essere a basso costo;

ii) deve essere resistente, ossia capace di operare per molti anni con un minimo di interventi di manutenzione;

iii) deve fornire un'efficienza di rivelazione quanto più prossima al 100%;

iv) deve consentire la ricostruzione di tracce di muoni cosmici ed essere quindi costituito da (almeno) tre piani di rivelazione;

v) deve possedere una risoluzione spaziale di qualche centimetro (in entrambe le coordinate orizzontali) per la localizzazione in ogni piano di rivelazione del punto di attraversamento di un muone; ciò consentirà l'estrapolazione della traccia ricostruita del muone a parecchi chilometri di quota nell'atmosfera e quindi l'individuazione, per più tracce ricostruite in diversi rivelatori, di un punto comune di produzione degli eventi di energia estrema costituiti da sciami cosmici;

vi) deve possedere una risoluzione temporale sufficiente per permettere che muoni cosmici rivelati in diversi apparati situati a grande distanza l'uno dall'altro possano essere messi in correlazione l'uno con l'altro tramite un dispositivo GPS (questo implica una risoluzione temporale di alcune decine di nanosecondi) e per garantire inoltre la discriminazione, tramite coincidenze tra almeno tre piani di rivelazione, del fondo accidentale generato da segnali di rumore (ovviamente una risoluzione dell'ordine del nanosecondo è utile a questo scopo).

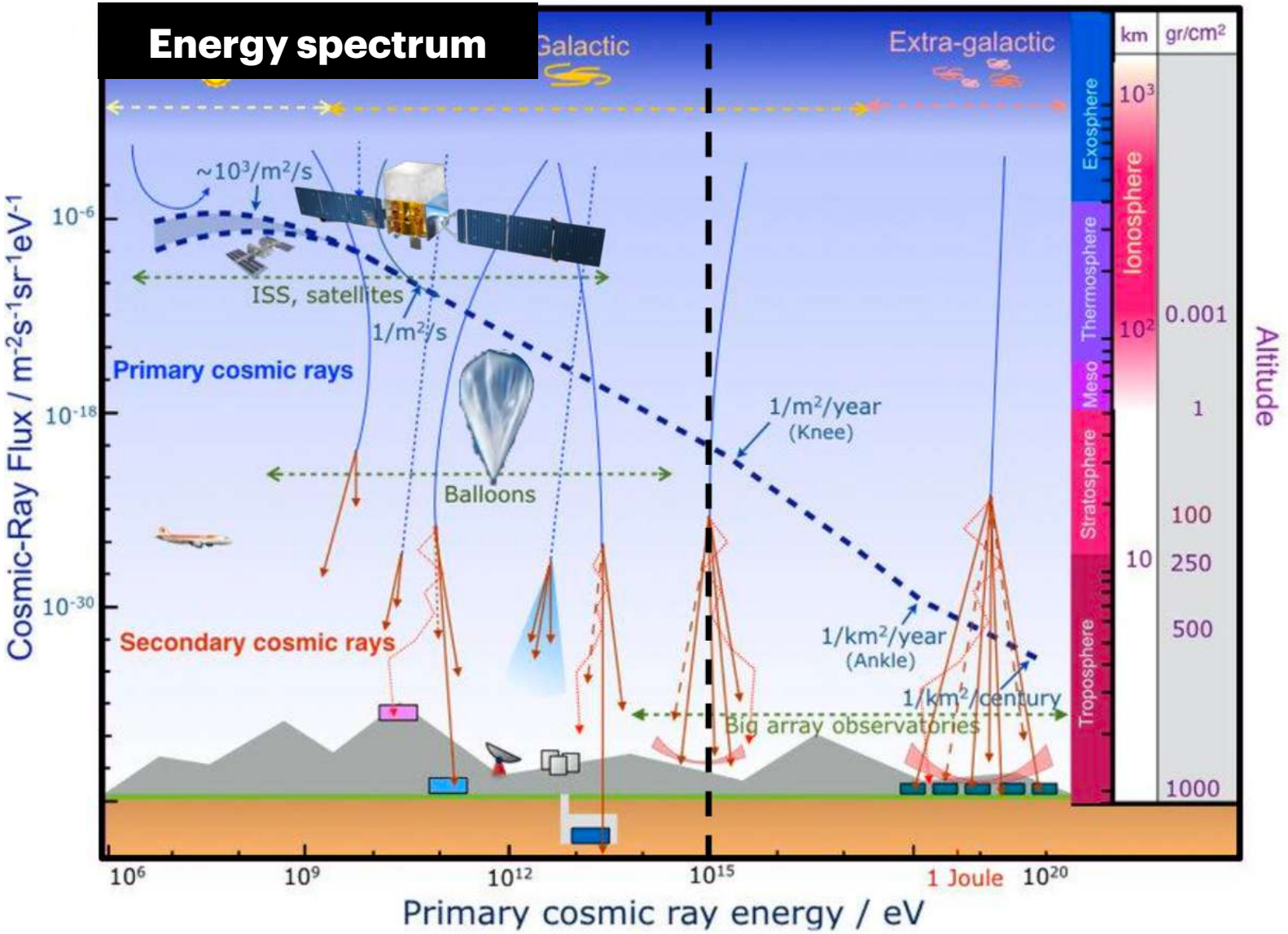
The Requirements

- Wide area&low cost
- Robust for long time operations
- High efficiency
- Muon Taking capability, i.e. 3 planes
- cm^2 spatial resolution
- O(10ns) time resolution for coincidences (GPS) and better for TOF measurement

The main goals of the Project and the planned steps:

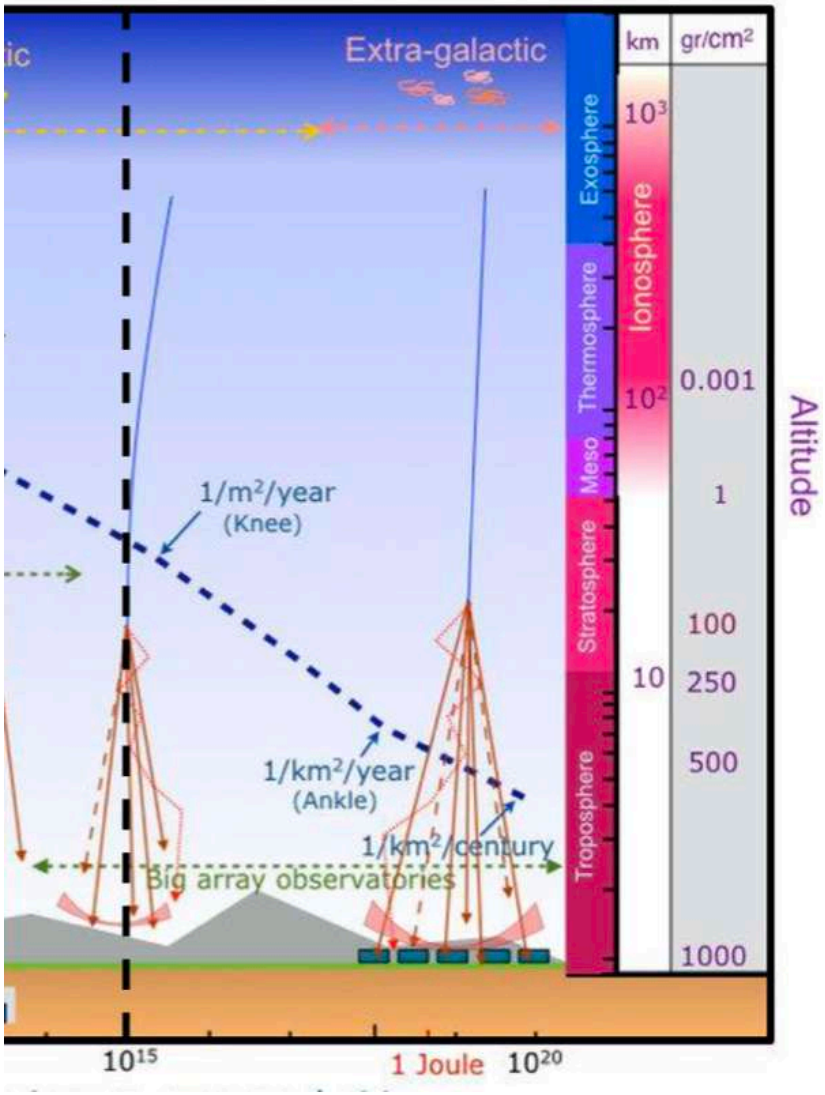
- Build a number of cosmic ray telescopes based on MRPC technology, with direct involvement of school teams
- Install and operate them in Italian high schools
- Measure cosmic ray data, analyse and discuss the results

Cosmic Rays



Primary cosmic rays produce a steady vertical intensity of ~70 muons/m^{-2}s^{-1}sr^{-1}

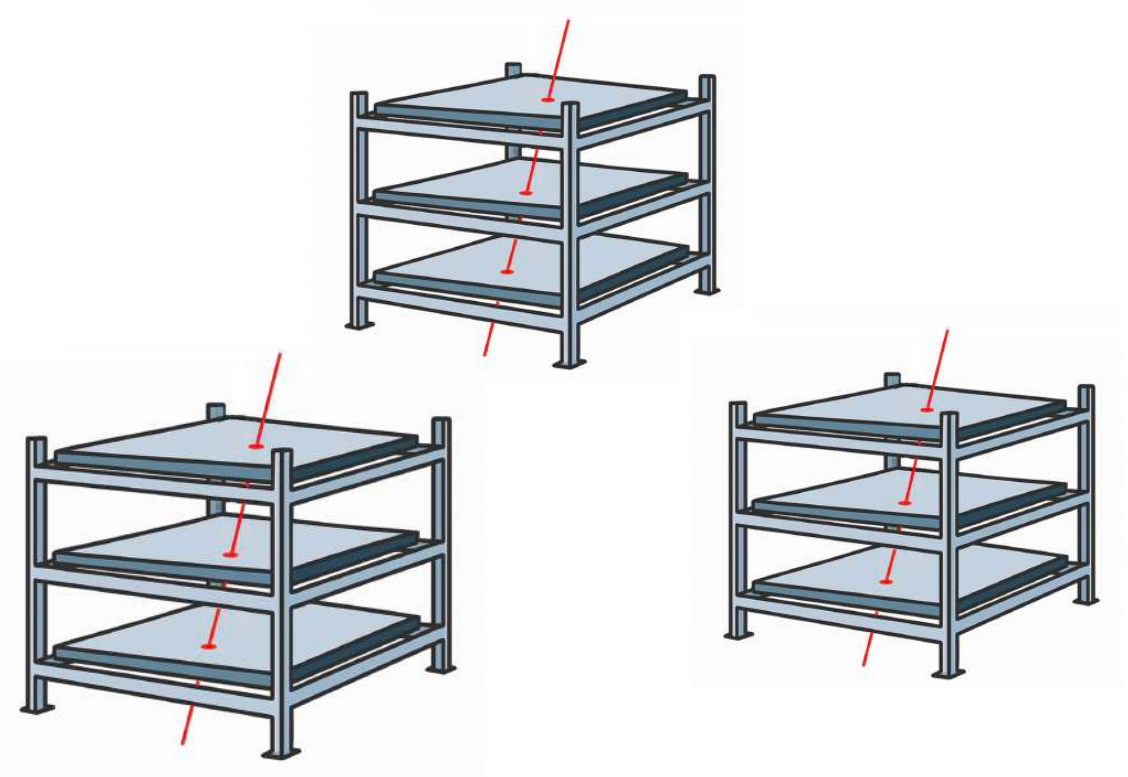
EAS



Ground based array of detectors may detect the Extensive Air Showers produced by primary cosmic rays interaction in the atmosphere

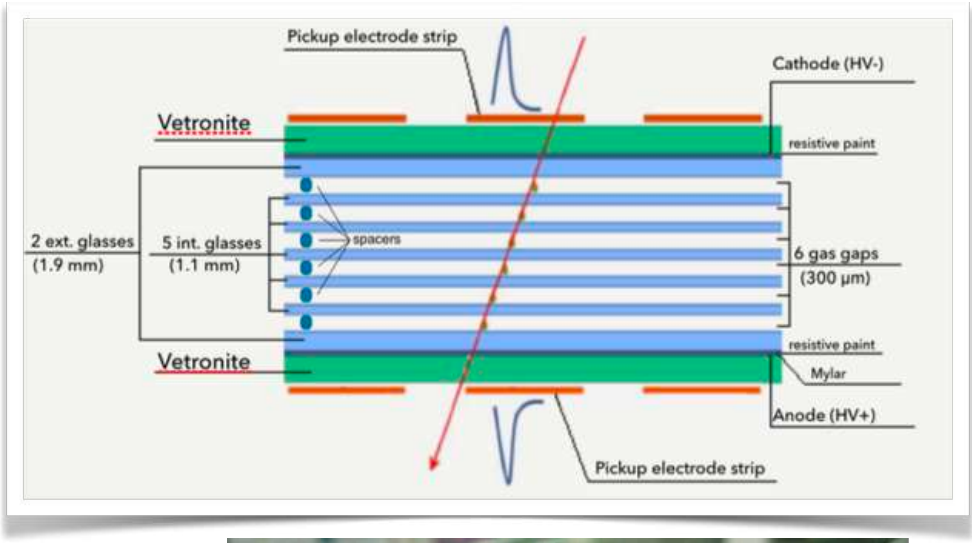
The lonely chance to measure the most energetic CR!

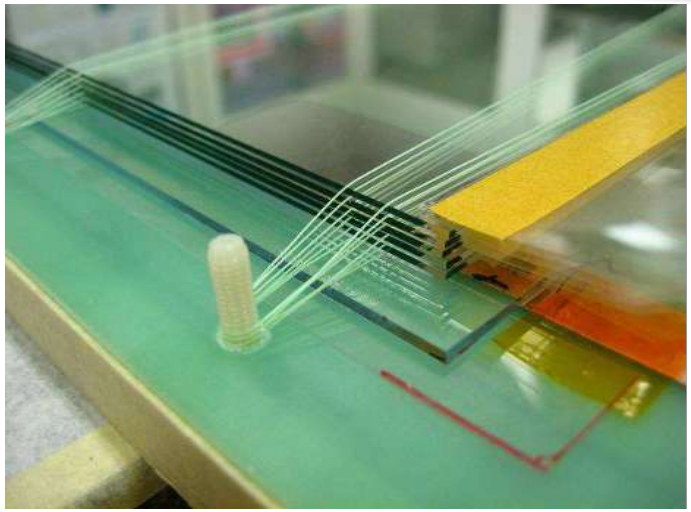
But continuous monitoring of the CR at ground provide many information too!

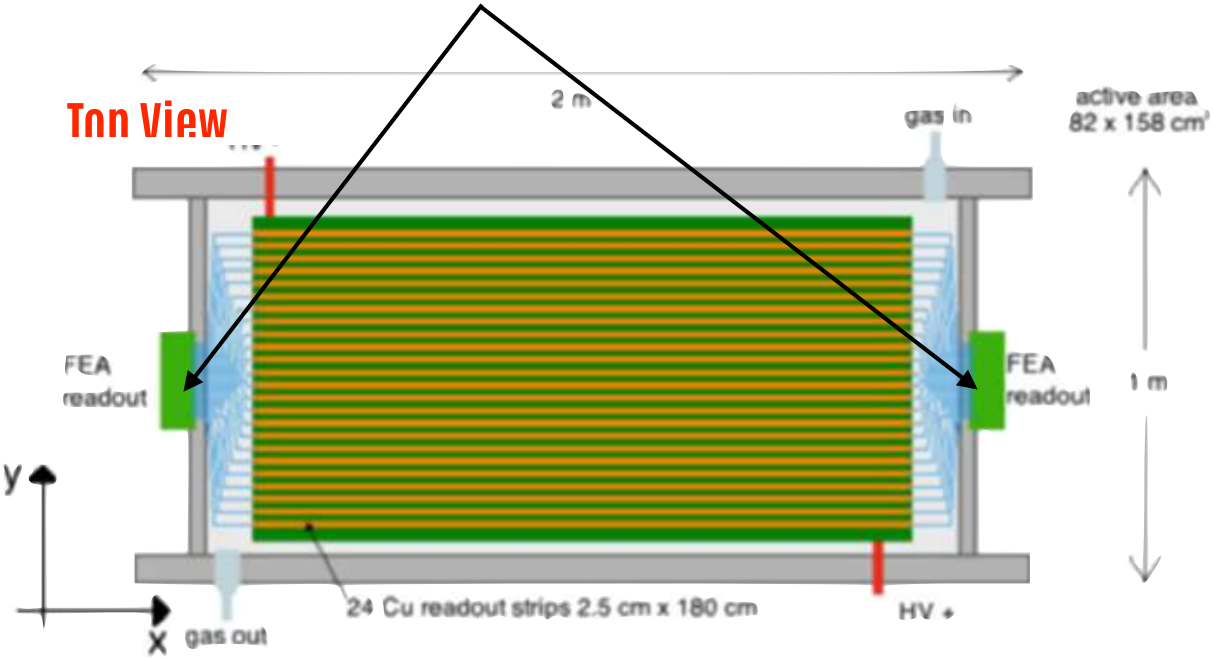


The EEE Project MRPC

- Wide area (~ 2 m²) MRPC
- 6, 300 (250) μm thick, gas gaps
- 1.9 mm thick glass plates used as electrodes (resistive paint)
- 1.1 mm thick glass plates floating
- Fishing line as spacer
- 24 readout copper strips (both anodic and cathodic)
- Till 2019 operated with 98%-2% r134a-SF_6 (streamer free operation) gas mixture, then…we will see later
- ~ 20 kV (±10 kV). DC/DC converters close to the detector to avoid HV cables in schools
- NINO based FE cards



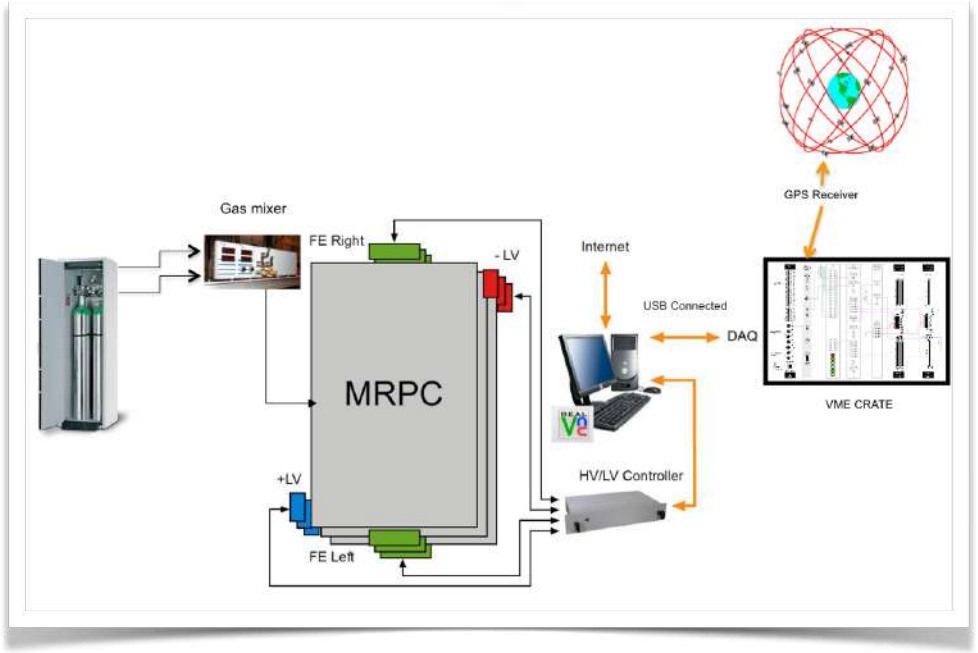




X coordinates by signal arrival time difference
Y strip with signal

The Telescope

The EEE telescopes are constituted by 3 Multigap Resistive Plate Chambers



- Muons are detected and reconstructed with ~cm² spatial resolution and hundreds of ps time resolution.

- The telescopes are GPS synchronised for offline analysis on time correlated events

- Data from each station are sent to the Bologna INFN CNAF for the track reconstruction and storage (next slide)

School & Students involvement

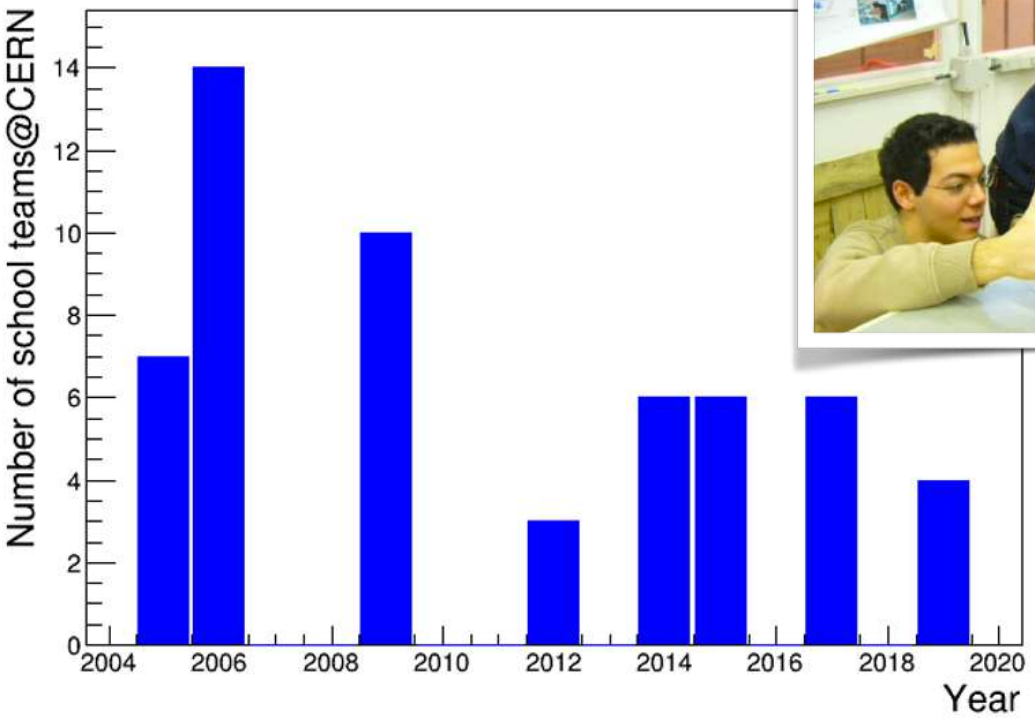
EEE is a cosmic rays observatory with detectors installed mainly inside Italian high schools

Students are involved in all the phases of the experiment!

—>An innovative approach to young students involvement!

- they build at CERN the detectors for the telescope.
- they are involved in the installation at school, in the operation and monitoring of the telescopes.
- they participate to monthly online and in presence (bi-annual pre COVID) meetings presenting their analysis or attending masterclasses.

Some numbers



- From 2005 to 2019 56 school teams went to CERN
- Each team from 5 to 10 students & 1-2 teachers
- A total of 300-400 students and 60-90 teachers participated to MRPC construction
- In addition, we had students from Albania, Russia, France, Sweden, Greece, Austria, Norway, Germany,…
- High school teams also followed 1-3 weeks internship programs (HSSIP), visits to CERN and ALICE and other activities

> 180 MRPCs built along the years –> Largest (in terms of total detector area) system using MRPCs

The computing and data infrastructure

Data collected @ CNAF and automatically reconstructed

Progetto Extreme Energy Events - La Scienza nelle Scuole

EEE MONITOR - DQM

[Official address: http://eee.centrofermi.it/monitor]

Ultimo aggiornamento: ore 13:37 - lunedì 10 febbraio 2025 [by e3monitor]

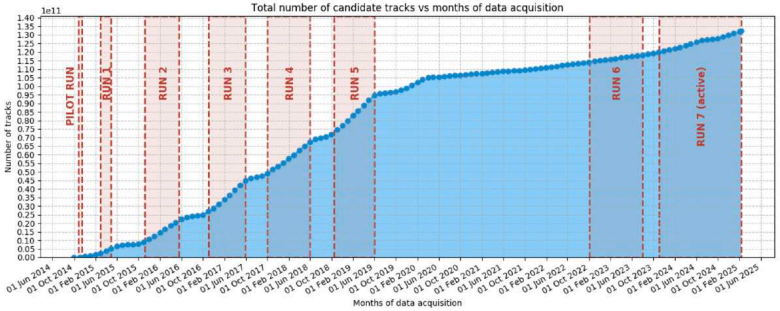
[EEE Monitor] RUN 7 - Telescopi con nuova miscela di gas ecosostenibile

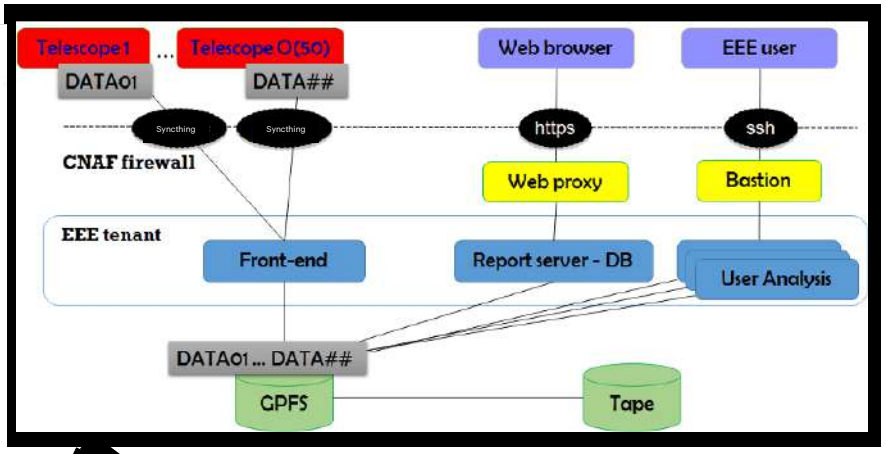
Total number of candidate tracks (X^2<10) in the database: 132236661803

ELOG RUN7

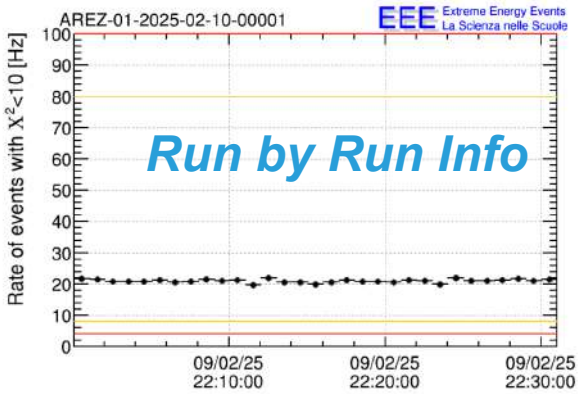
DATA REQUEST

Today's plot of the total number of candidate tracks vs months of data acquisition

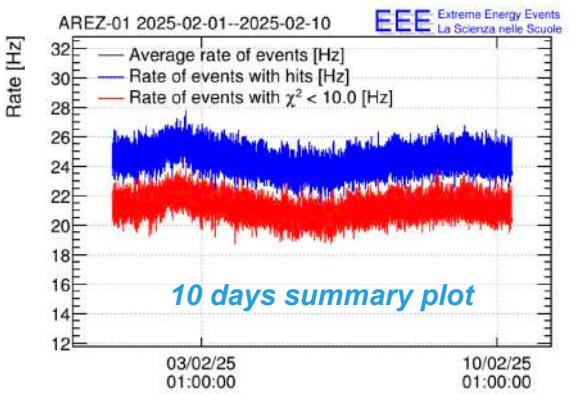




School	Day	Time	Name of the last trasferred File	Number of Files trasferred today	Name of the last File analyzed by DQM	DQM daily report	RATE of Triggers for the last Run in DQM	RATE of Tracks for the last Run in DQM	Link DQM
ALTA-01 [Event Display]	sab 15 febbraio	11:08	ALTA-01-2020-02-15-00032.bin	0 [History]	ALTA-01-2020-02-15-00032.bin	16/02 [History]	31.0	10.0	ALTA-01
ANCO-01 [Event Display]	dom 08 marzo	19:08	ANCO-01-2020-02-25-00002.bin	0 [History]	ANCO-01-2020-02-25-00022.bin	13/02 [History]	22.0	15.0	ANCO-01
AREZ-01 [Event Display]	lun 10 febbraio	13:09	AREZ-01-2025-02-10-00025.bin	26 [History]	AREZ-01-2025-02-10-00024.bin	10/02 [History]	25.0	21.0	AREZ-01
BARI-01 [Event Display]	ven 07 febbraio	11:44	BARI-01-2025-02-07-00001.bin	0 [History]	BARI-01-2025-02-07-00001.bin	10/02 [History]	10.0	10.0	BARI-01
BOLO-01 [Event Display]	lun 10 febbraio	13:01	BOLO-01-2025-02-10-00042.bin	43 [History]	BOLO-01-2025-02-10-00042.bin	10/02 [History]	43.0	32.0	BOLO-01
BOLO-02 [Event Display]	lun 10 febbraio	12:59	BOLO-02-2025-02-10-00029.bin	28 [History]	BOLO-02-2025-02-10-00029.bin	10/02 [History]	19.0	14.0	BOLO-02
BOLO-03 [Event Display]	lun 10 febbraio	12:58	BOLO-03-2025-02-10-00032.bin	121 [History]	BOLO-03-2025-02-10-00032.bin	10/02 [History]	33.0	29.0	BOLO-03



Run by Run Info

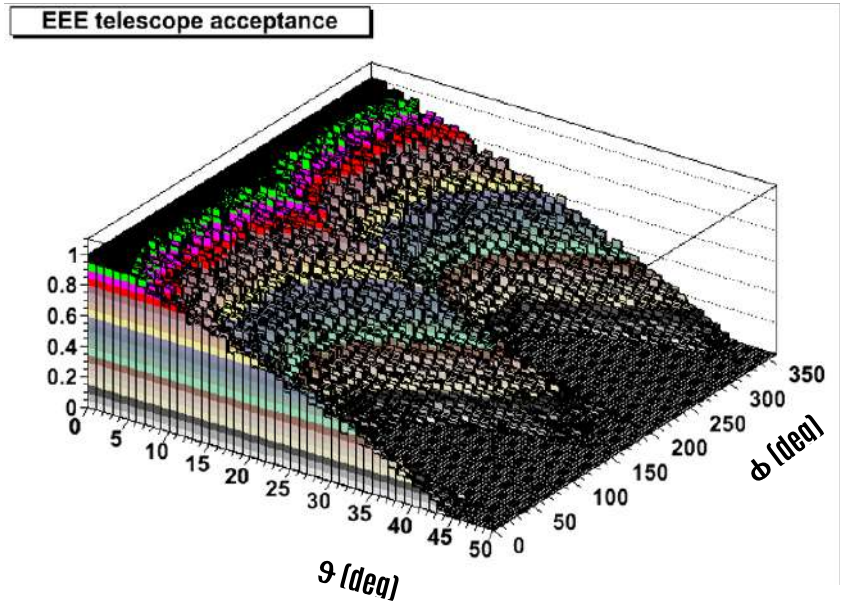


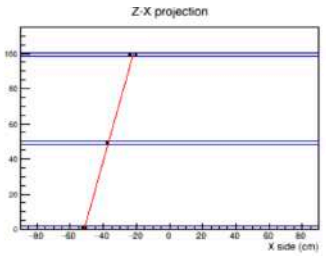
10 days summary plot

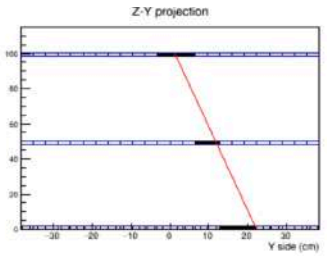
Open Data

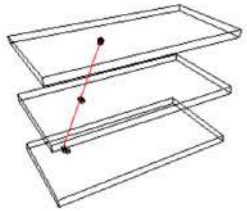
Geometrical acceptance and efficiency

Due to its geometry the telescope is sensitive to a wide angular region (0-360° in φ), (0-50° in ϑ) with a (ϑ, φ)-dependent acceptance.





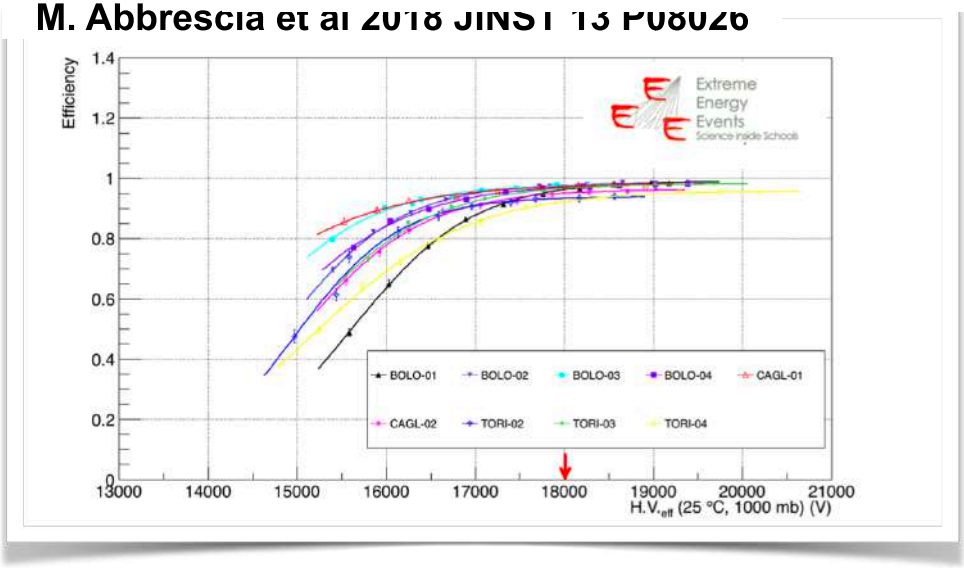


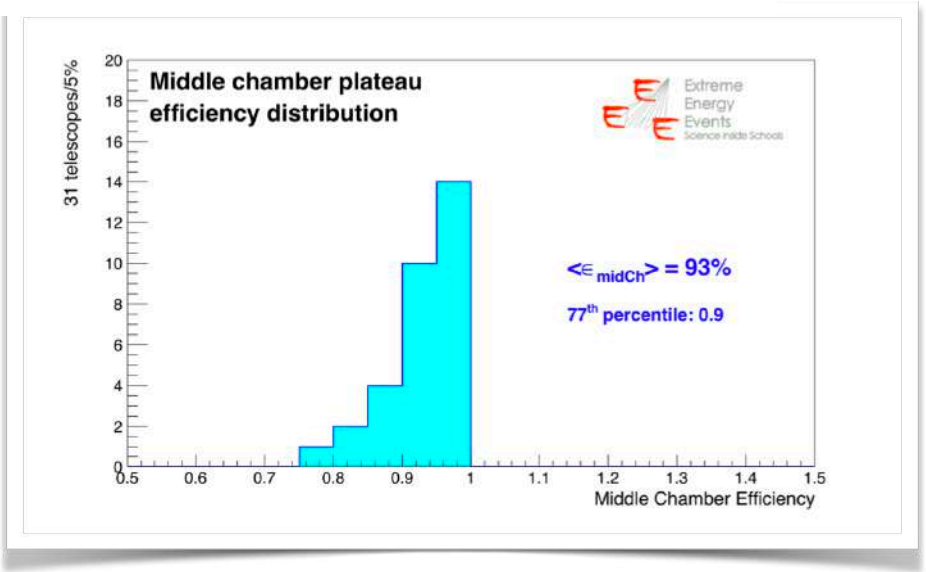


BOLO-02
event 29193
Date 11/2/2025
Run 00022
UTC: 14:17:40

Detection efficiency measured both with cosmics and beams at CERN iound larger than 90% for most of the telescopes

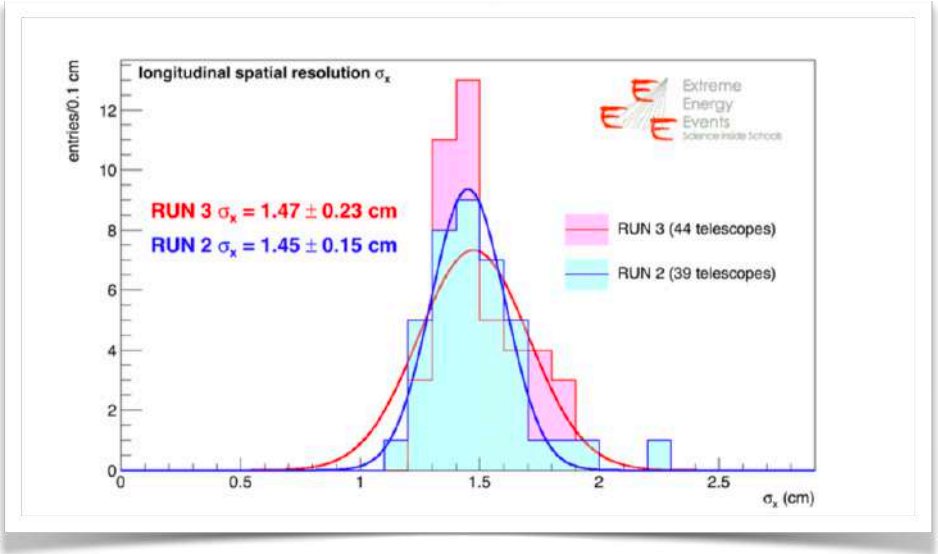
M. Abbrescia et al 2018 JINST 13 P08026

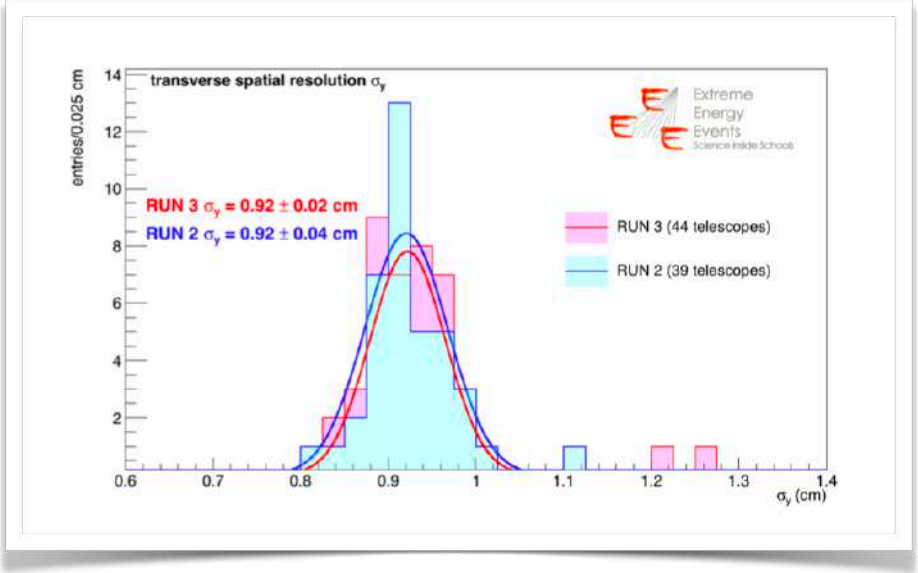




Spatial and Time Resolution

Spatial resolution measured with data taken during normal operations, RUN 2 and RUN 3 → **~1 cm²**

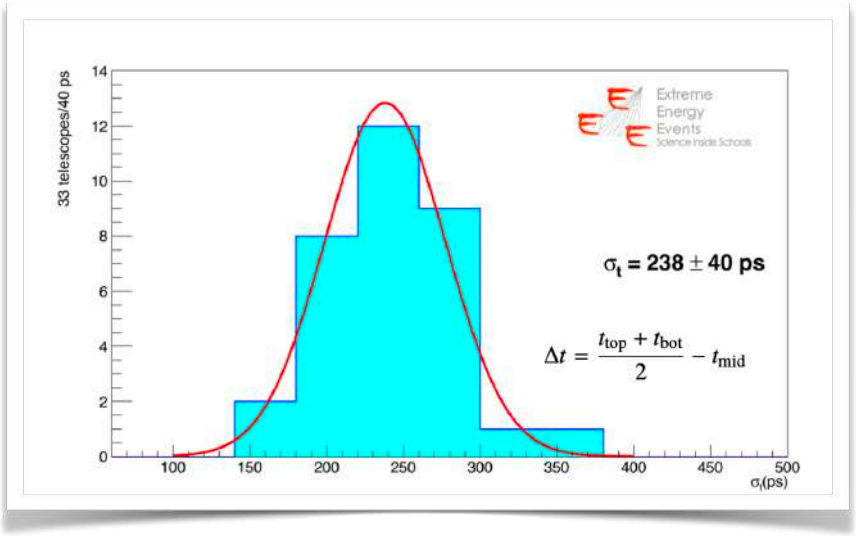




Time resolution measured with data taken during normal operations, for 33 telescopes; the average time resolution is given by the gaussian fit and is

σ_t = 238 ps

Time slewing correction applied



Measuring Cosmic rays

And publishing results

The EEE telescopes are able to measure the cosmic ray flux as a function of the

- Zenithal direction (polar angular distribution)
- Azimuthal direction (azimuthal angular distribution)
- Time
- Geographical location (lat. & long.)
- Elevation above the sea level
- Possible time correlations with additional detector and/or telescopes

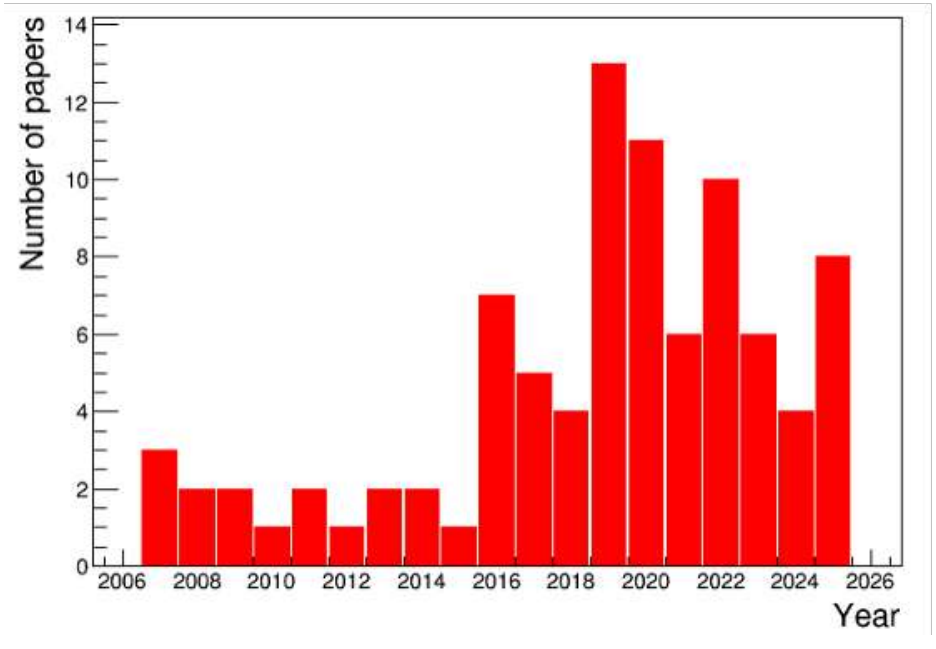
These (and other) possibilities allow to carry out a variety of different investigations.

Updated plot of EEE yearly published papers

84 in total

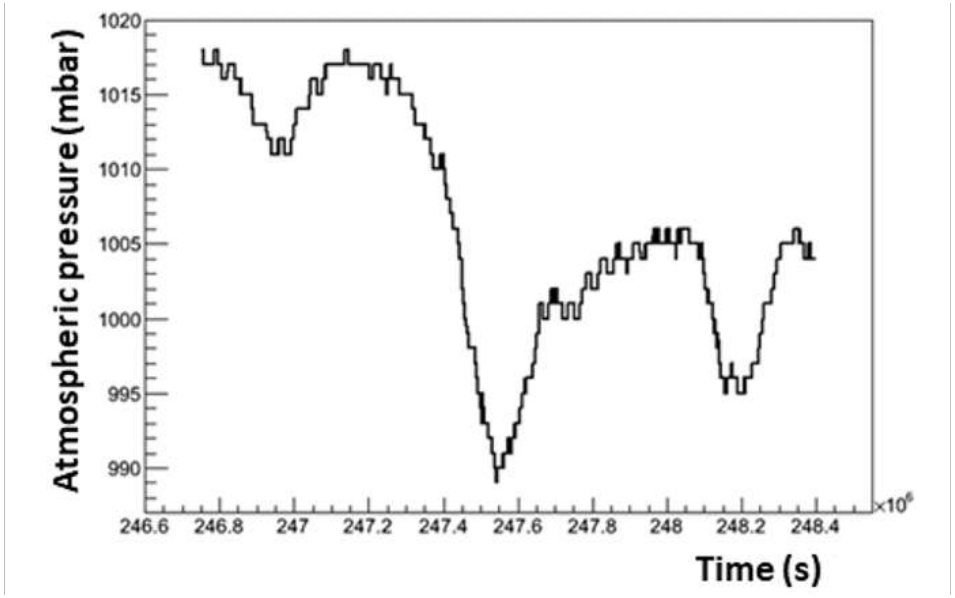
including Conference Proceedings in refereed Journals

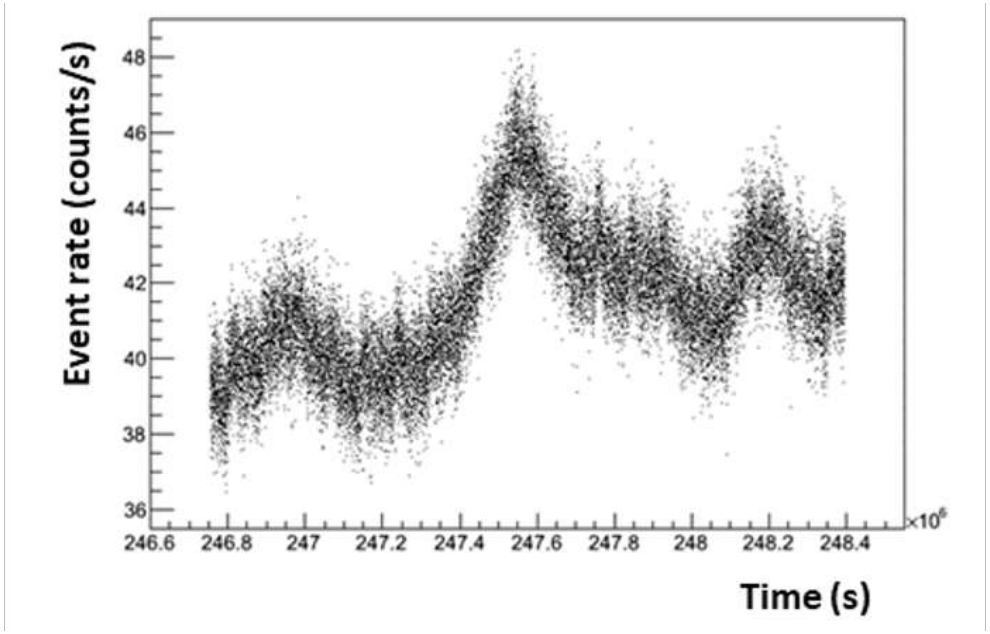
Few examples in the following

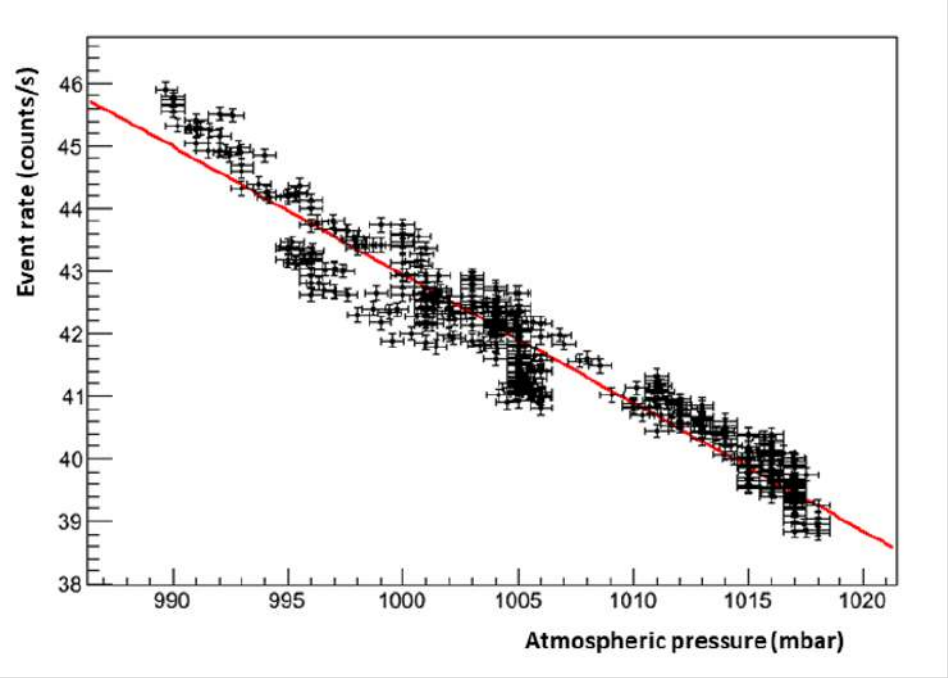


Cosmic rays flux & atmospheric pressure

An anticorrelation between rate & atmospheric pressure variations is expected



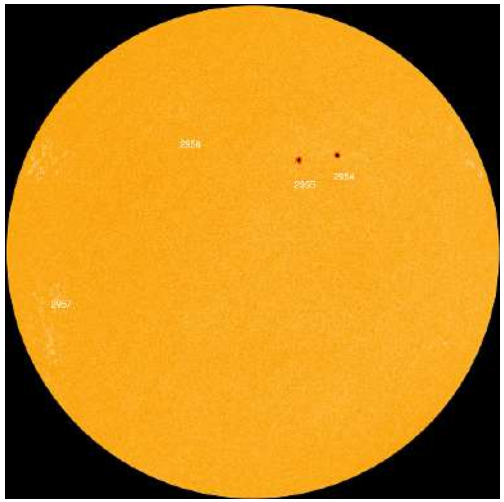


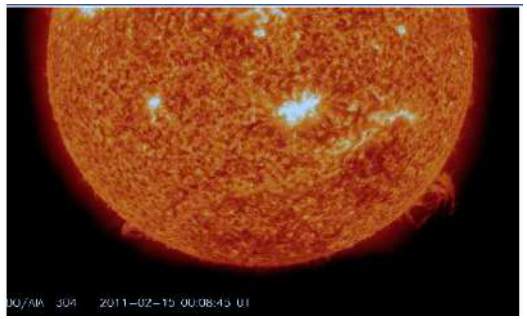


A «barometric» coefficient may be extracted from data to correct them before additional analyses.

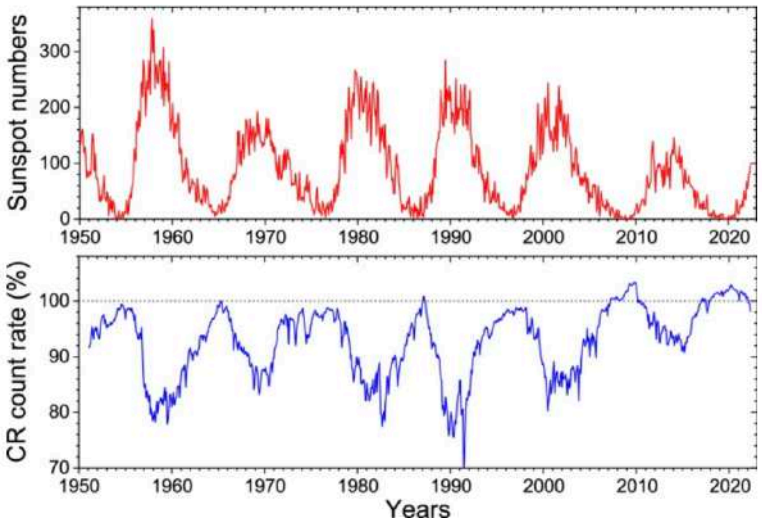
School teams involved in such analysis from the very beginning.

Cosmic rays flux & the Sun





The Sun also affects in different ways the cosmic ray flux through its periodic and catastrophic (aperiodic) phenomena

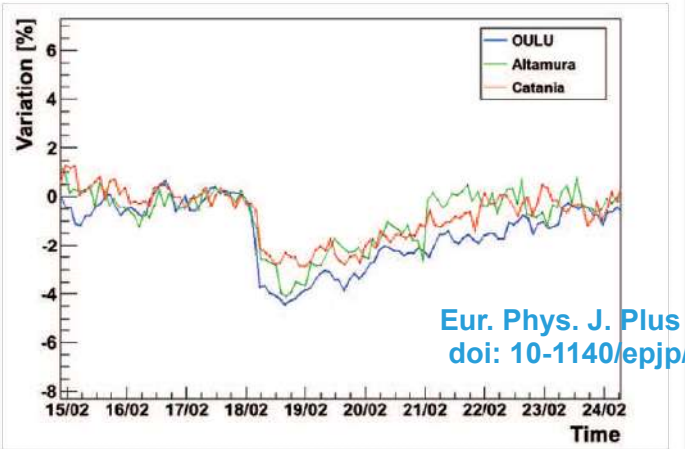


The cosmic ray flux on Earth is anticorrelated with the number of sunspots (11-years cycle)

Scott Forbush
1937 first obs.

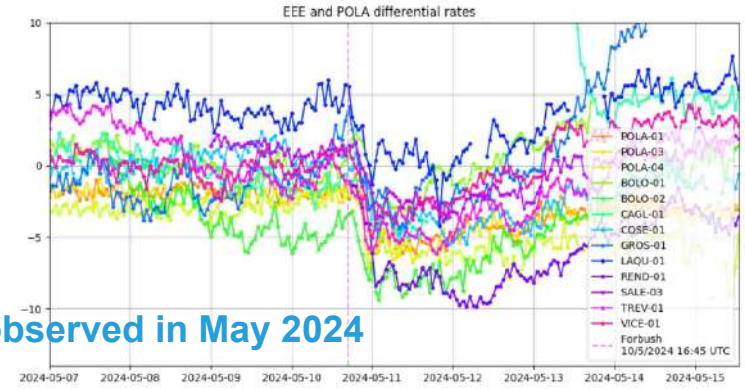
Catastrophic (aperiodic) phenomena as solar flares/ coronal mass ejection -> Forbush decreases (planetary phenomena)

The first Forbush observed in 2011



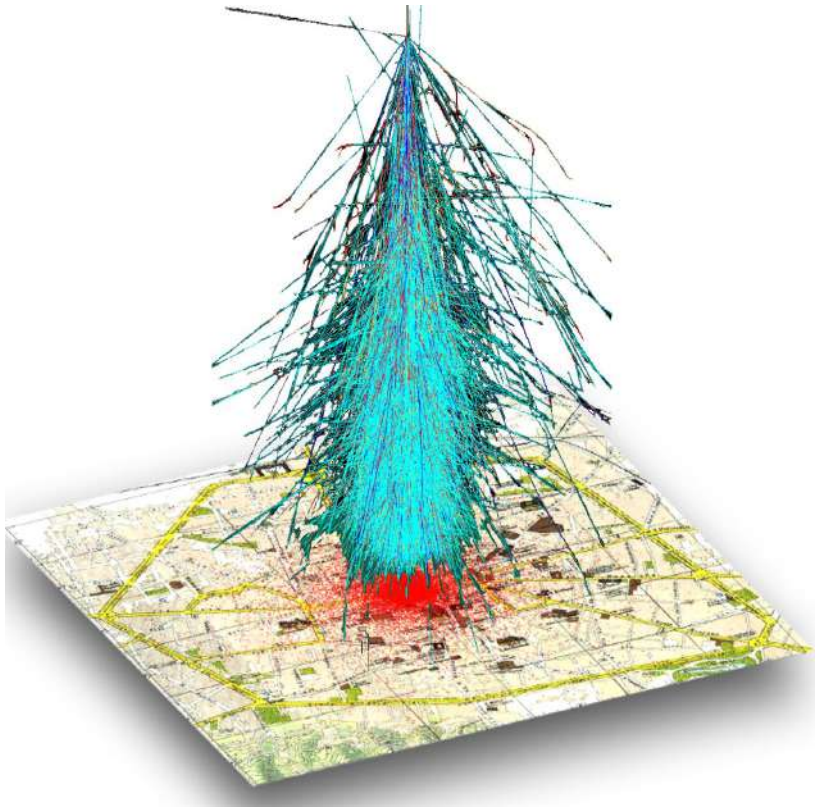
Eur. Phys. J. Plus (2011) 126, 61,
doi: 10-1140/epjp/i2011-11061-5

EEE & Forbush effect



The one observed in May 2024

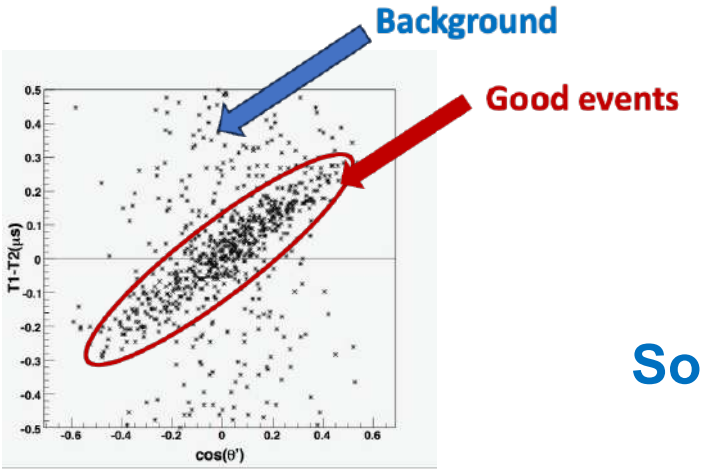
Extensive air showers

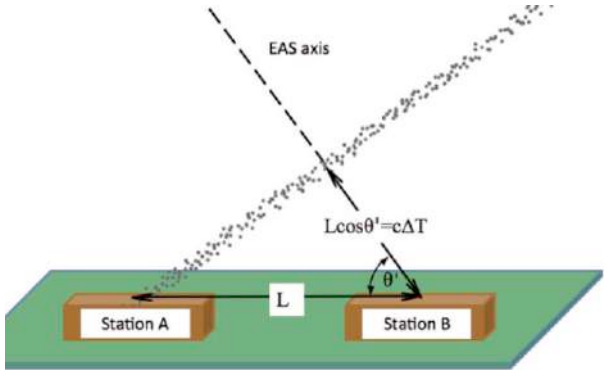


Detection at ground of the secondary cosmic rays produced in extensive air showers induced by primary particles (mostly protons) in the Earth atmosphere.
We detect coincidence events in two or more telescopes apart.
Time synchronisation (through GPS) between individual telescopes is an essential part of the game.

Important steps to improve the analysis were:
a) the correction to the time difference between telescopes by the knowledge of the incoming direction of the particles
b) The selection of multitrack events

Something that simple scintillation detectors cannot do.

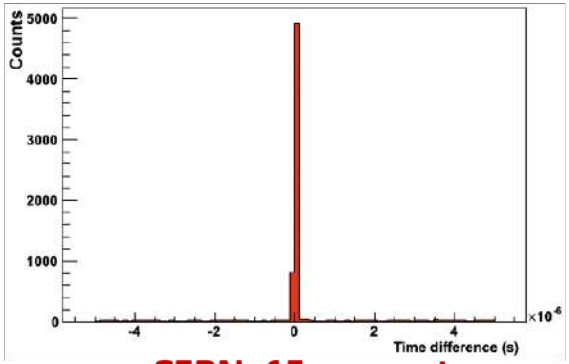




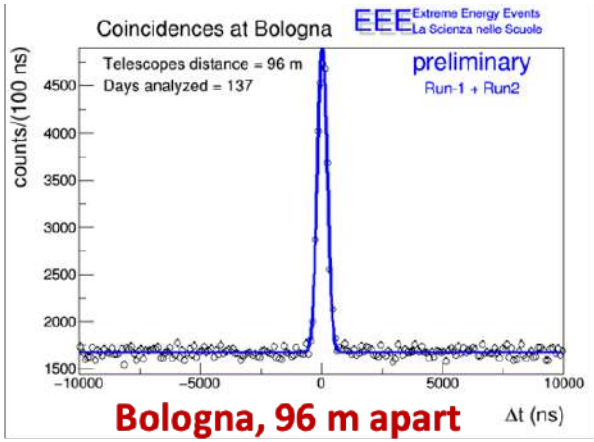
Something that simple scintillation detectors cannot do..

Extensive air showers by telescope coincidences

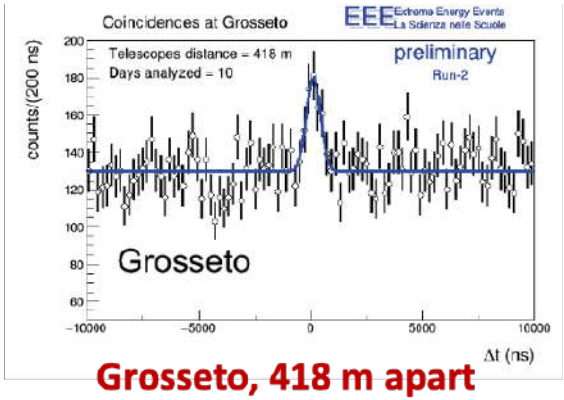
The yield of coincident events and the signal-to-noise ratio depend on the relative distance between telescopes



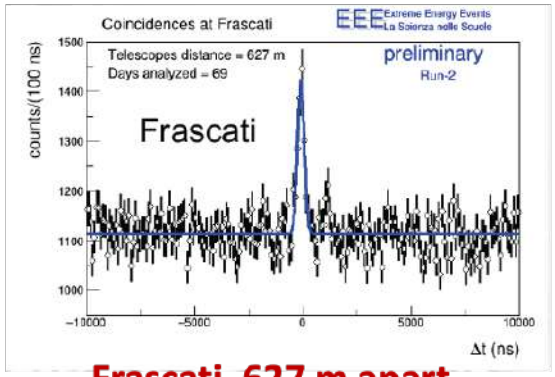
CERN, 15 m apart



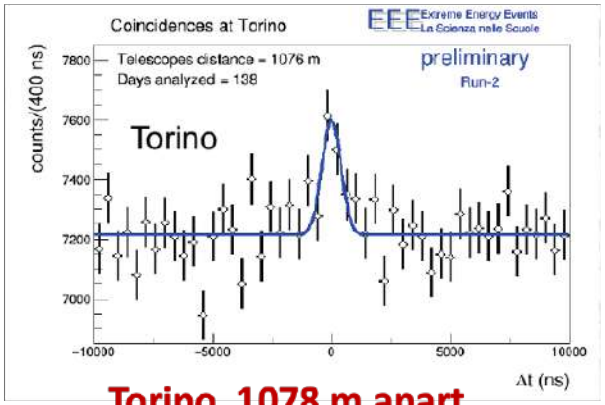
Bologna, 96 m apart



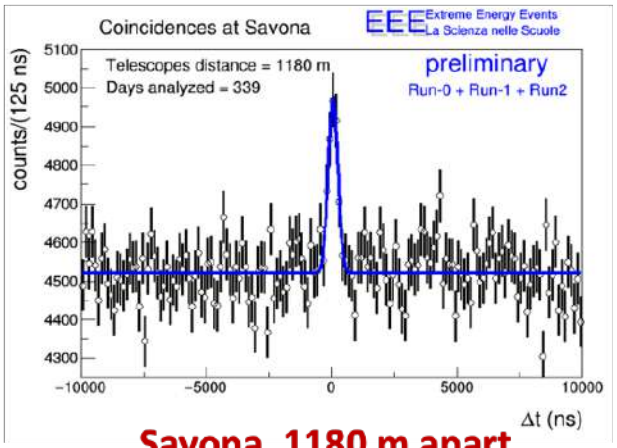
Grosseto, 418 m apart



Frascati, 627 m apart



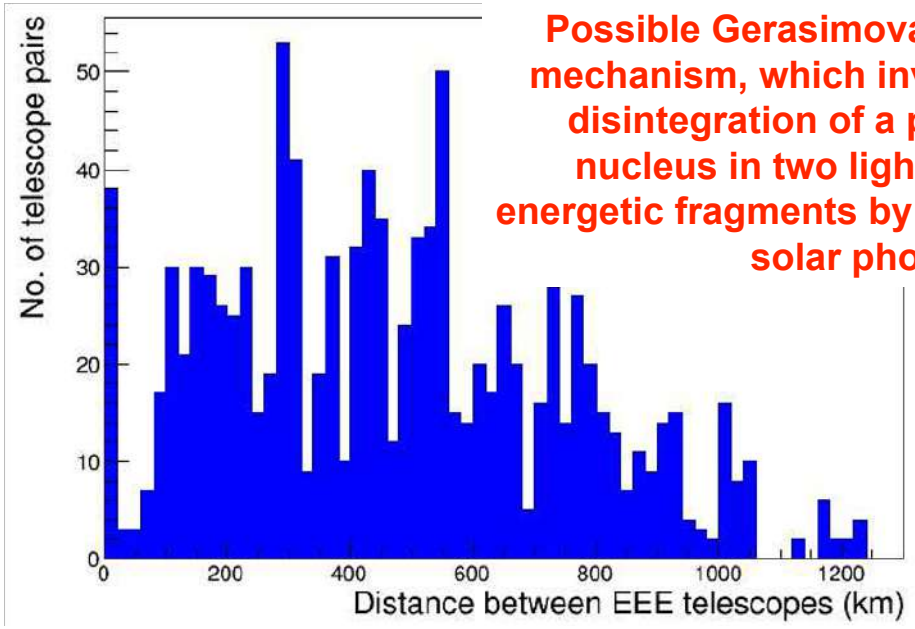
Torino, 1078 m apart



Savona, 1180 m apart

Searching for long distance correlations

The possibility to observe «exotic» events due to correlated showers at large distance has been debated, but no clear evidence found so far

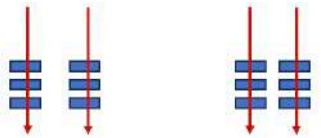


Possible Gerasimova-Zatsepin (GZ) mechanism, which invokes the photo disintegration of a primary heavy nucleus in two lighter but highly energetic fragments by interaction with a solar photon

The EEE network, with its sparse topology, has the capability at least to search for these events

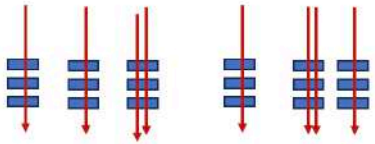
Several investigations performed over the last 10 years data, with different analysis strategies

Strategy 1: Search for coincidences between telescope pairs located in the same town (cluster sites)

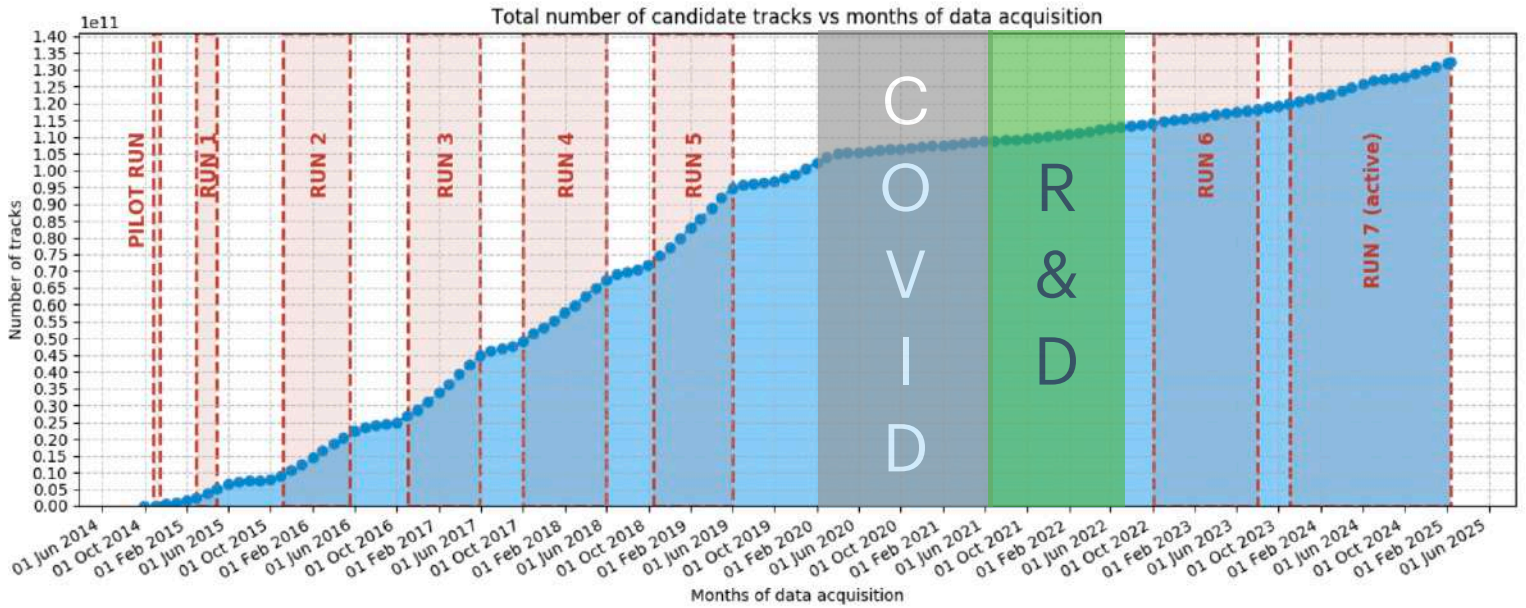


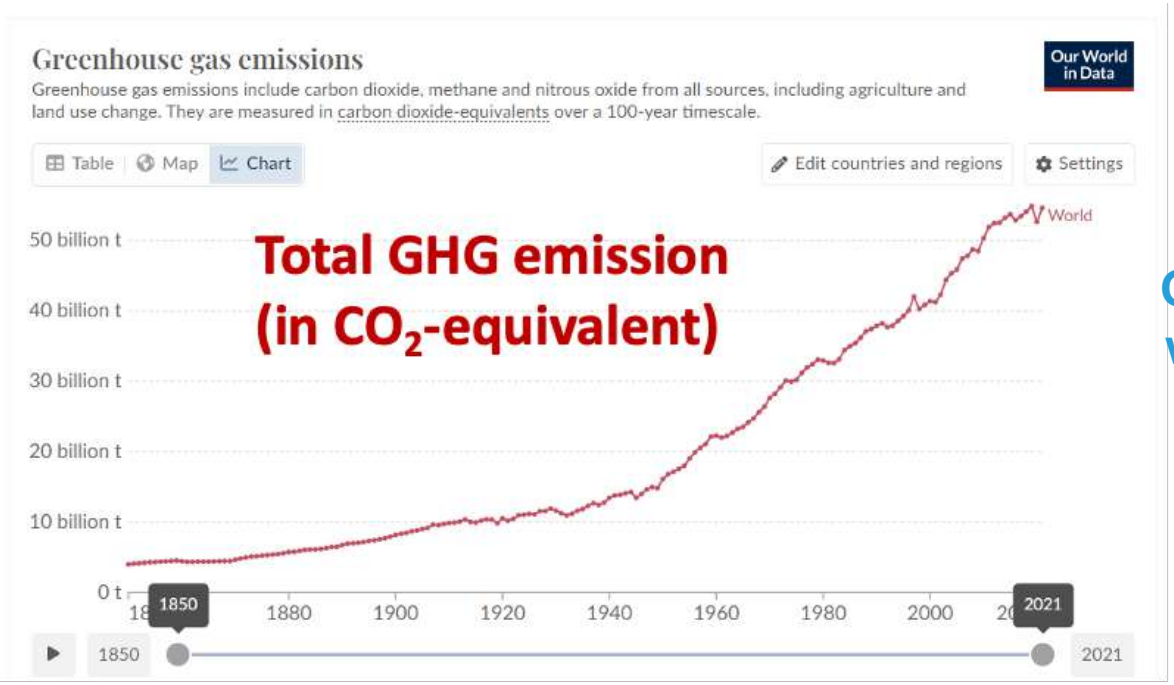
Strategy 2: Search for two-fold coincidences between multitrack events in any telescope pair

Strategy 3: Search for n-fold coincidences between telescopes



The Green Transition





In the last years considerable efforts spent by EEE to reduce GreenHouse Gas (GHG) emission with a lot of work involving many people in the Collaboration

The Solution

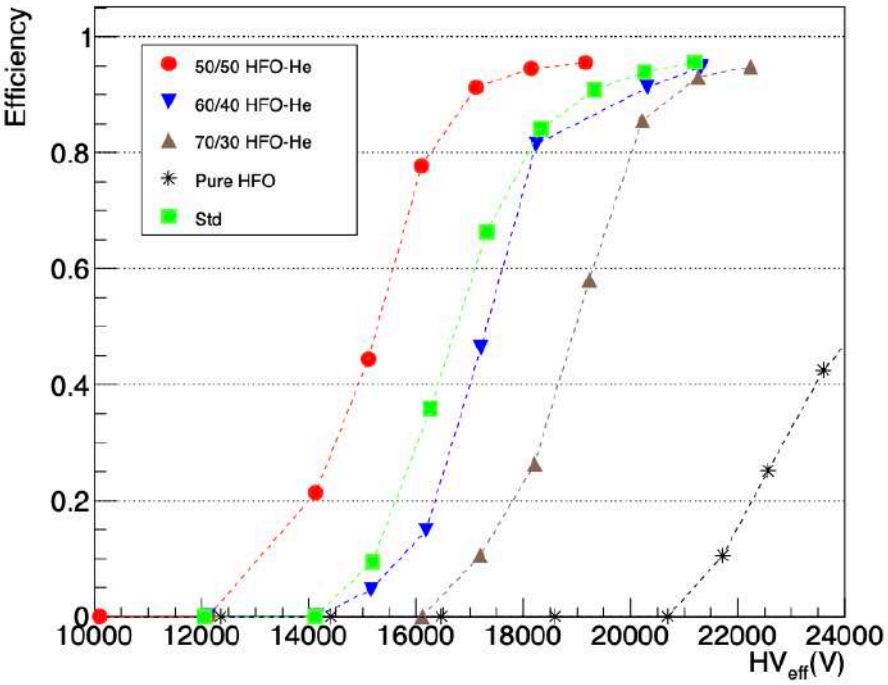
- Reduced gas leakage
- Reduced gas flow
- R&D on a Test gas recirculation system (Still Ongoing)
- Identified a new eco friendly gas mixture*: C3H2F4 + He (GWP ~6)

*it has to be:

- Binary
- Maximum HV ~ 20k kV
- Lowest GWP

PAPER · OPEN ACCESS 2024 *JINST* 19 P11003

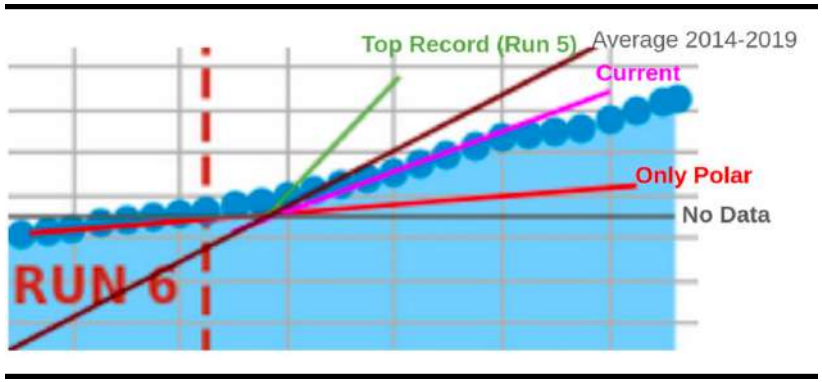
First results on new helium based eco-gas mixtures for the Extreme Energy Events Project



Performances compatible with the one obtained with standard mixture not only in terms of detection efficiency, but also in terms of spatial resolution.

The lower time (260 ps vs. 240 ps) precision does not impact the absolute timestamp of the particles, keeping the capability to correlate particles simultaneously detected by different telescopes of the EEE network.

Operations in the network are now restarting



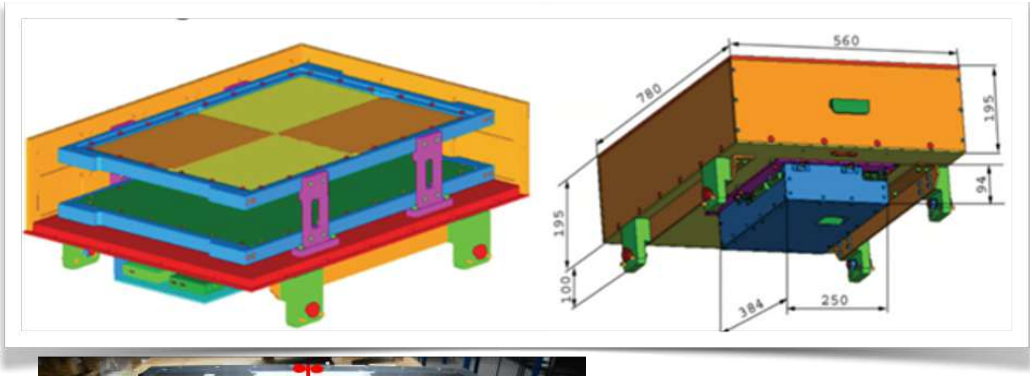
The PolarquEEEst mission

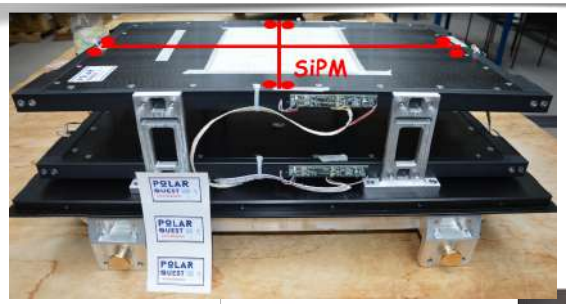
-The Polar Quest 2018 mission was a scientific multidisciplinary exploration of Svalbard archipelago.

-The EEE Project contribute to the mission with a cosmic ray detector, POLA-R, to observe Cosmic Rays at very high latitude.

-3 POLA-R detectors were assembled at CERN by high school students: POLA-01, installed on Nanuq sailboat, POLA-02 installed in a Norwegian high school (Nesodden) and POLA-03 installed in an Italian high school (Bra)

- 2 Plastic scintillator planes
- distance between planes: 11 cm
- 4 Tiles for each plane: 30 cm x 20 cm
- 2 SiPMs per tile (16 SiPMs in total)
- 15 Watts power consumption
- 50 kg

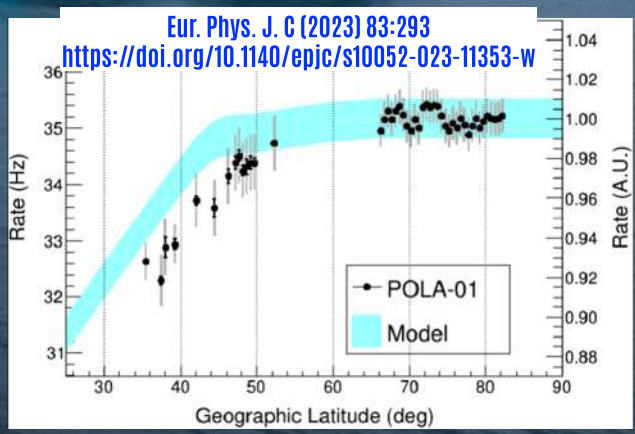


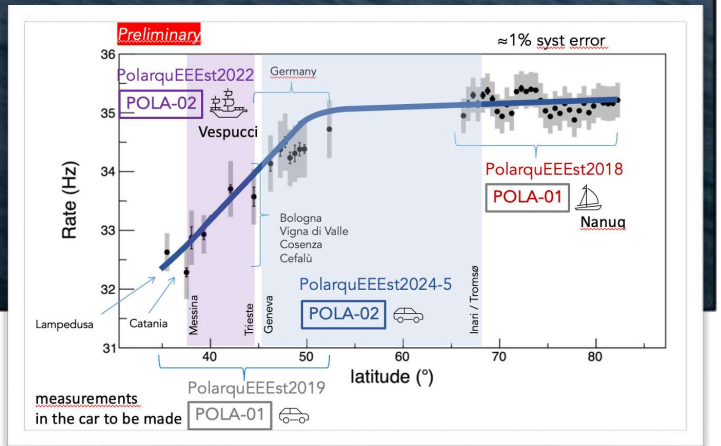


The measure

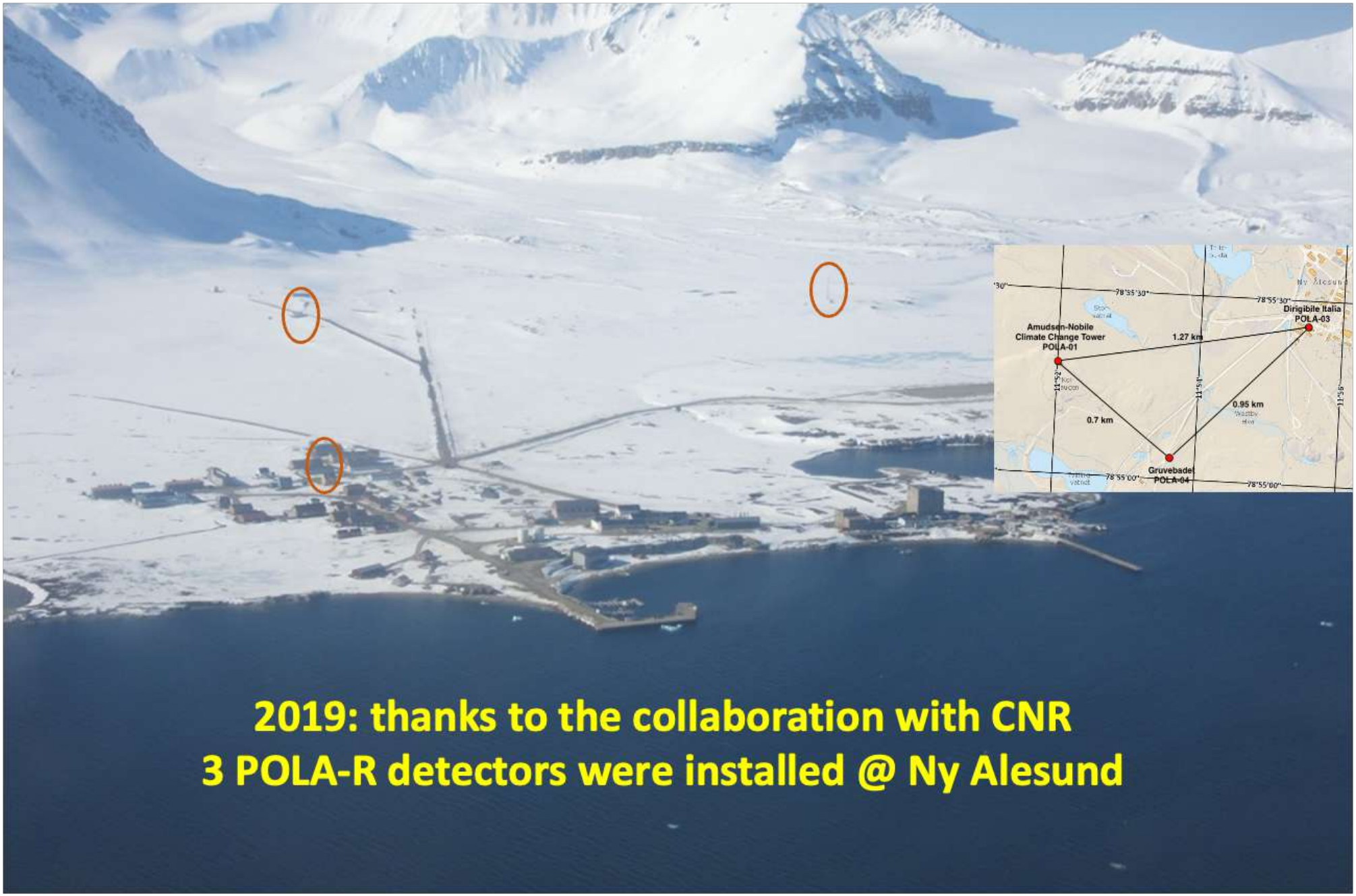
Nanuq sailed for 45 days covering about 3500 NM (≈ 6500 km) reaching the limit of the polar pack ice 82° 07'N 25° 23' E

The POLA-01 cosmic ray detector has taken data almost continuously for about 984 hours collectin more than 100 million muon tracks

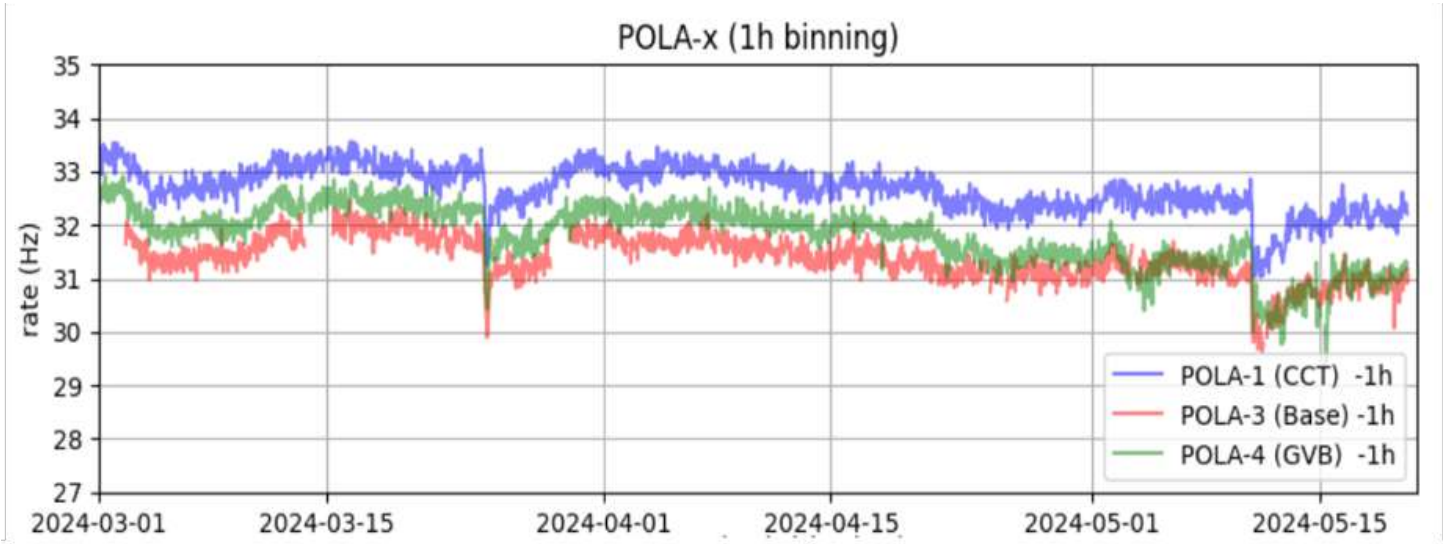


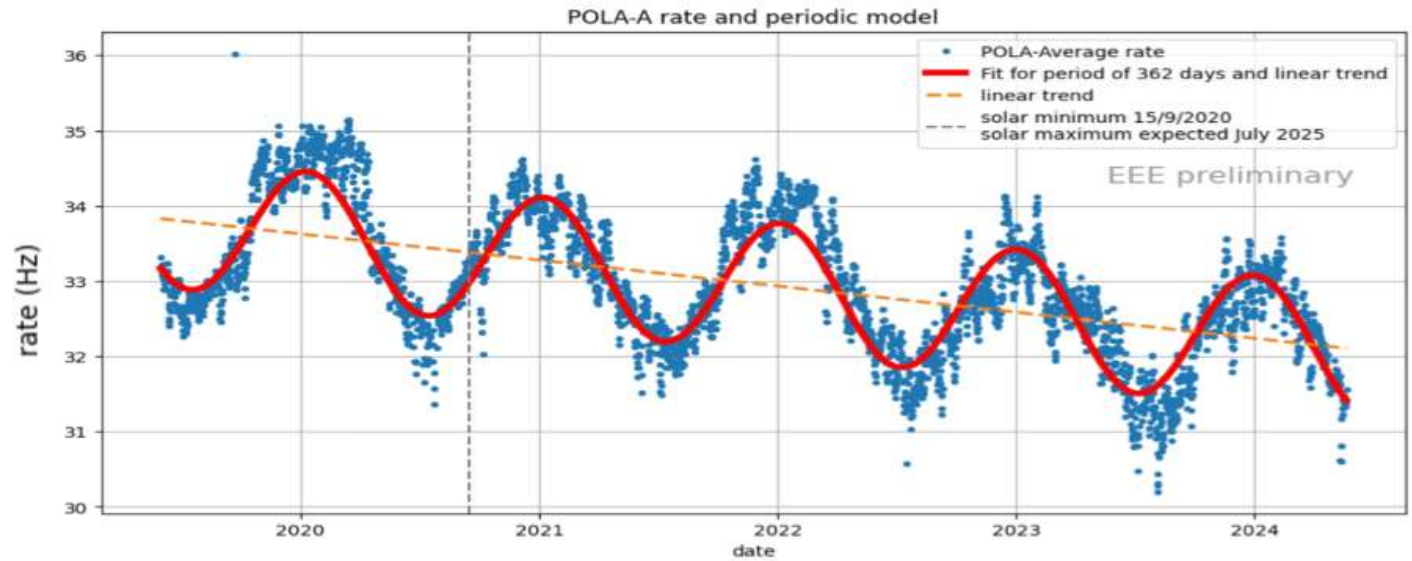


PolarquEEEst 2019



Monitoring the CR flux at highest latitudes





Middle of May 24 we observed on of the most intense Solar flare (Forbush effect)

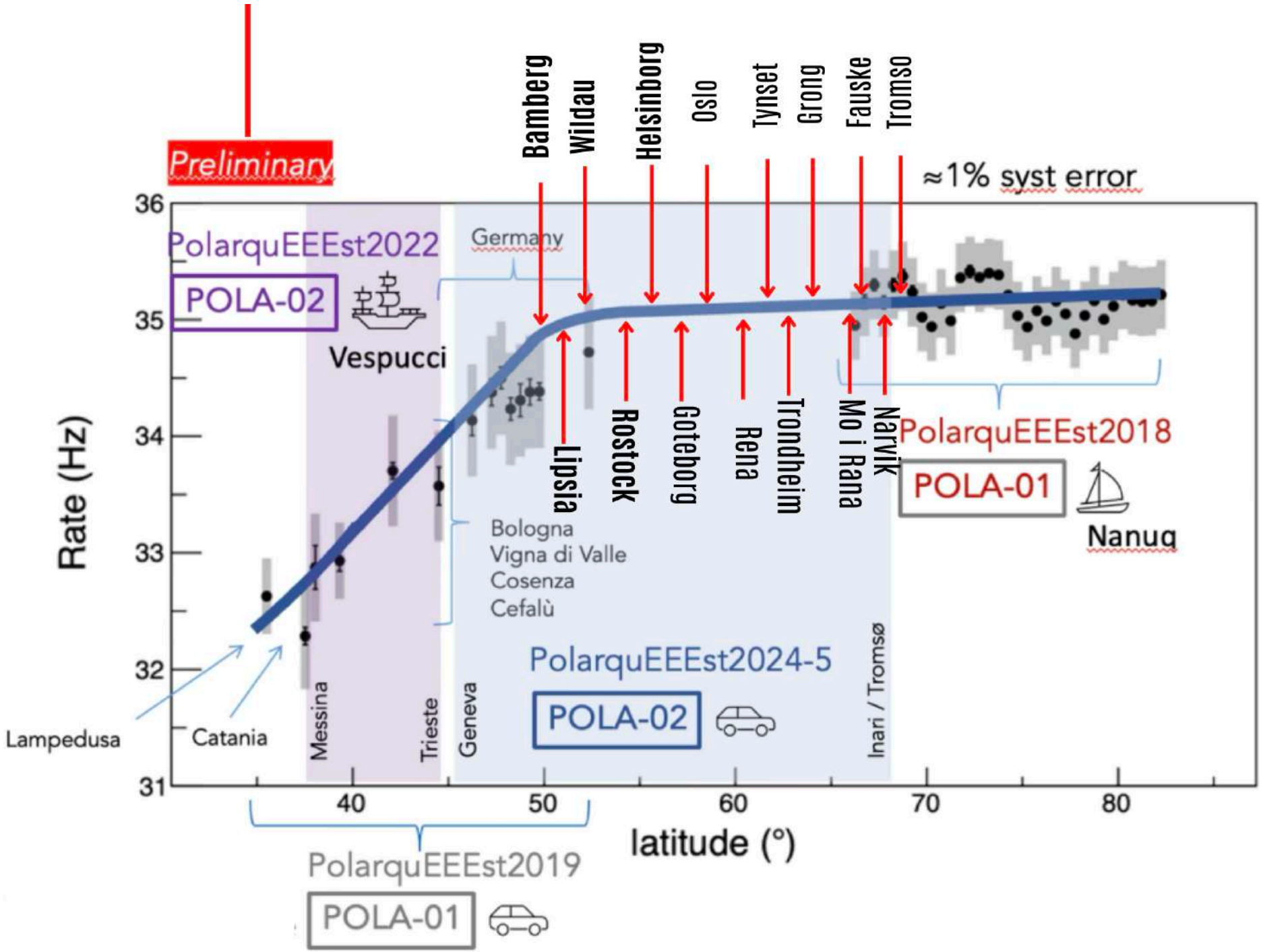
Annual modulation + Solar cycle effect (CRIS-MAC 2024)

Study ongoing

The measure of cosmic-ray flux time dependence can be a potential monitoring tool for spotting changes related to the environment, solar activity or other causes.
Collaboration with CNR and on site neutron monitor

And the portable detector allows to..

And the portable detector allows to..



The Outreach Program

- A large part of our activities is addressed to involve the high school community in the scientific and technical aspects of an advanced research

- This is usually done in different ways:

  - Taking part in the construction, operation of detectors, checking the status of data taking,...
  - Participate to monthly meeting and presenting the results of their work
  - Attend general EEE meetings with lectures, masterclasses, exp.activities...
  - Prepare and submit projects

- The pandemic has introduced a further challenge for a few years in all EEE activities

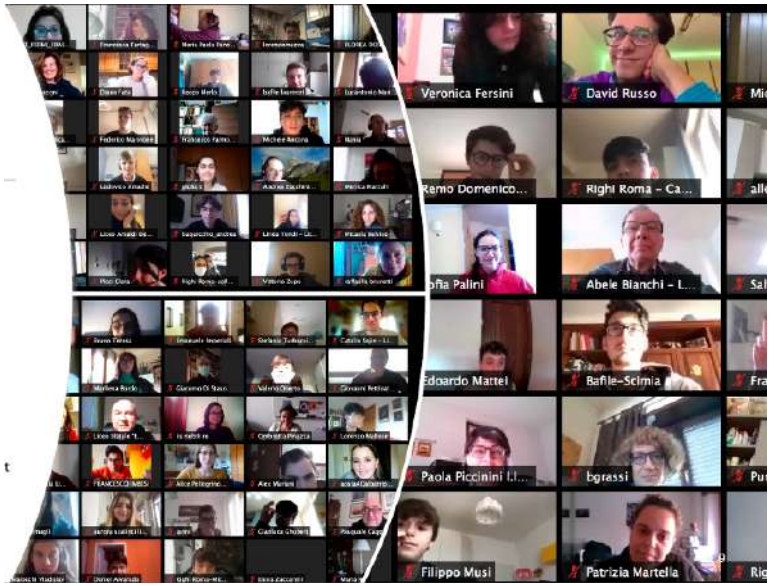
- EEE events in person have been restarted as done in the past...

Just few examples in the following

Meetings

Online

During the scholar year we organise monthly online meetings: they were devoted mainly to the EEE network operations, then during COVID we organised seminars; now the meetings are starting again to focus on the EEE operations and students participate actively to the meetings



In person

The annual in person general meetings are ON again! Unique experience for the students: masterclass, measurements and occasion to publish their work!

Outcome of activities

Some of the in person meetings are dedicated to perform analysis or measurements that are then published with the name of students and teachers as coauthors

GIORNALE DI FISICA VOL. LX, N. 2 Aprile-Giugno 2019
DOI 10.1393/gdf/i2019-10328-2

FISICA PER TUTTI

Gli studenti del Progetto EEE sulle orme di Eratostene per la misura del raggio della Terra

The students of the EEE Project in the footprints of Eratosthenes to measure the Earth radius

GIORNALE DI FISICA VOL. XLII, N. 2 Month year

Gli studenti del Progetto EEE misurano l'efficienza di rivelazione di muoni cosmici del telescopio situato presso i Laboratori Nazionali di Legnaro dell'INFN

Collaborazione EEE (*)

GIORNALE DI FISICA VOL. LIX, N. 3 Luglio-Settembre 2018
DOI 10.1393/gdf/i2018-10306-2

FISICA PER TUTTI

Come varia il flusso dei raggi cosmici con la quota? Basta chiederlo agli studenti del progetto EEE

How does cosmic ray flux vary with altitude? Let's ask it to EEE project students

Collaborazione EEE (*)

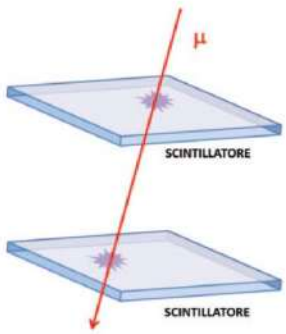
Centro Fermi - Museo Storico della Fisica e Centro Studi e Ricerche "Enrico Fermi" Piazza del Viminale 1, 00184 Roma, Italia

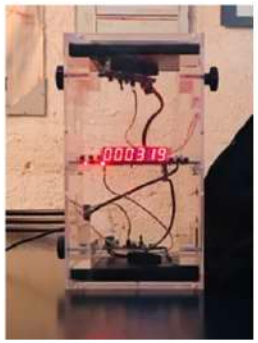
Docenti e Studenti delle Scuole

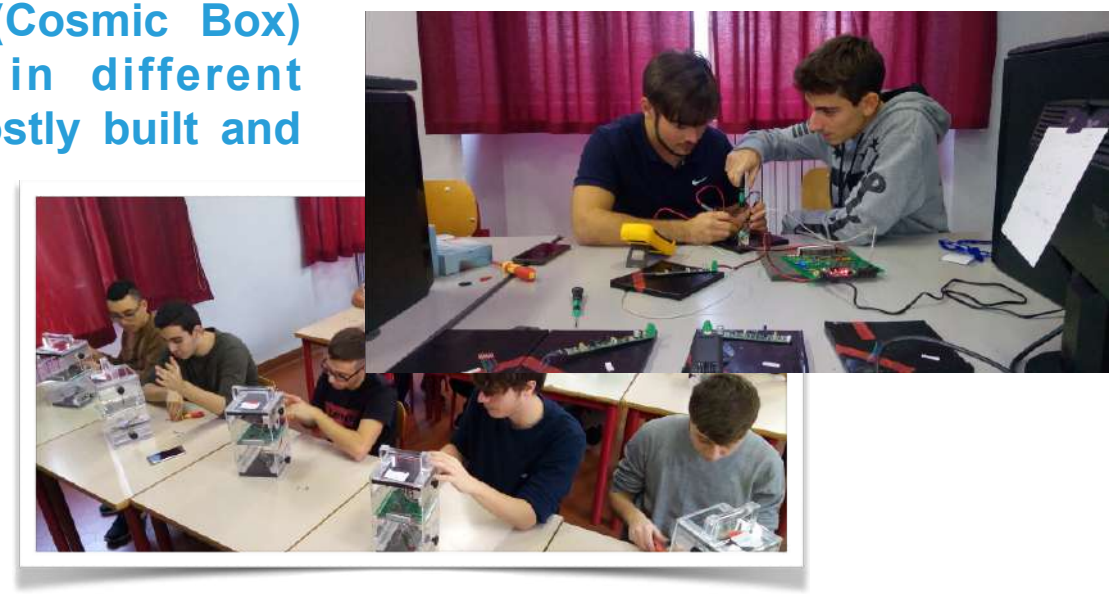
Maria Saveria Vicino (Prof.), Carlotta Zaccaria, Chiara Clemente
Liceo Statale Cagnazzi, Piazza Zanardelli 30, 70022 Altamura (BA), Italia
Laura Polenta (Prof.), Niccolò Cesaretti, Lorenzo Stefanini
Liceo Scientifico G. Galilei, Via S. Allende Gossens, 60131 Ancona (AN), Italia
Maria Alboni (Prof.), Nicola Romanelli, Giulia Marucci
Liceo Ginnasio Luigi Galvani, Via Castiglione 38, 40124 Bologna (BO), Italia
Andrea Zucchini (Prof.), Edoardo D'Aurelio, Francesco Potenza
Liceo Scientifico E. Fermi, Via Mazzini 172, 40139 Bologna (BO), Italia
Vasco Calzia (Prof.), Niccolò Di Julio, Andrea Soro

Other activities

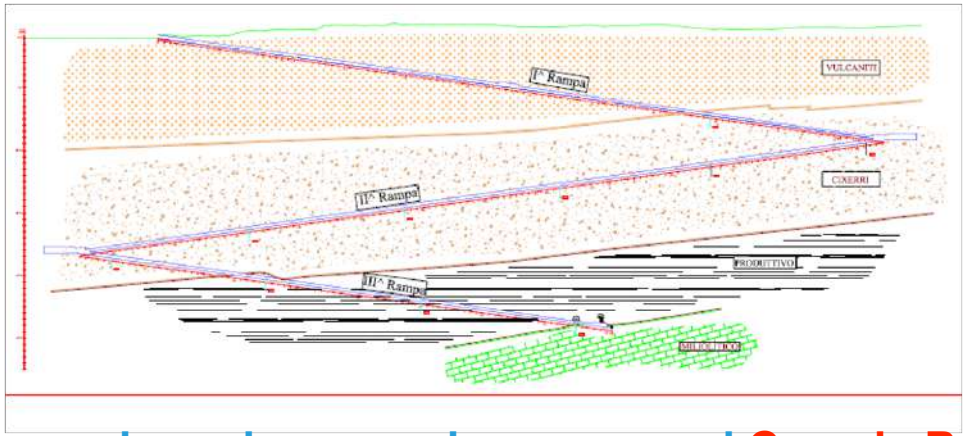
A number of additional detectors (Cosmic Box) were also built and employed in different measurements with cosmic rays, mostly built and operated by students

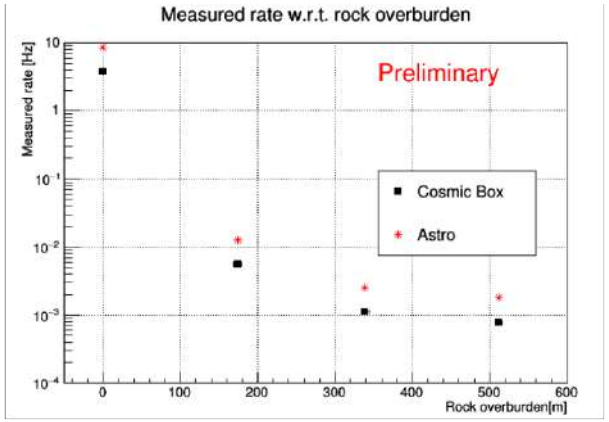






As example: a set of measurements with 3 Cosmic Box detectors carried out in the Nuraxi Figus-Seruci mine complex, close to Cagliari involving students





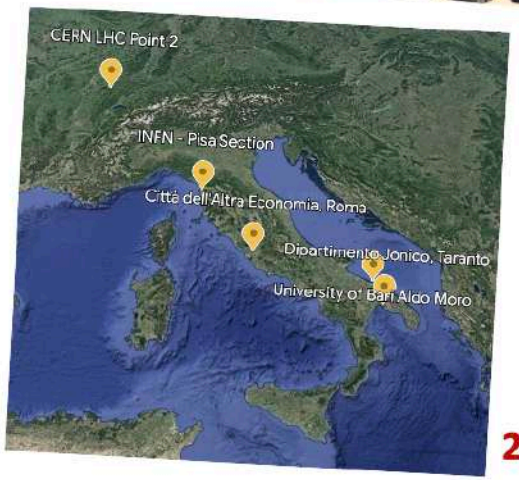
Many others and we also organise an annual Cosmic Box Contest: schools can submit a measurement project using the CB and then the best 10/12 projects are awarded with the instrument and have to report the results to the whole EEE collaboration.

..and more

Lab boat, Sardegna

International Cosmic Day/International Muon Week

Science festival, Cagliari



2023 European Research Night

Summary & next steps

The Extreme Energy Events (EEE) Project - "Science in Schools" is an experiment for measuring and studying Cosmic Rays at ground level, featuring an innovative and impactful program for promoting scientific culture

Strongly supported by CREF since the very beginning today is financed by CREF and INFN and many other institutions are involved: CERN, University Physics Depts, Majorana Center, SIF, INGV, CNR, INRIM)

What next in Short/Medium/Long Term

- Restart the operations on the whole observatory!
- Conclude the R&D on gas recirculation system
- Update/Upgrade old installation
- AI in the game?
- Possible general upgrade of the network using also other technology
- Some analysis ongoing to be completed:
    - cosmic ray flux periodicity
    - Forbush decrease in collaboration with neutron monitor
- Others to come (continue the LDC study, CR & climate, multi messanger events?)

EEE will continue the monitoring of the CR flux