The EEE – Extreme Energy Events Project of the Enrico Fermi Centre

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CENTRO FERMI is a research institution established in 2001 and devoted to interdisciplinary studies.

It aims to integrate the knowledge generated in different fields, and to promote discussion among top scientists with different areas of expertise, in order to create what Enrico Fermi would have liked to establish in Italy:

*a centre dedicated to frontier research in physics and to its wide applications for the benefit of humankind.*
Main Activities

The activities of CENTRO FERMI characterize its uniqueness:

1. **Grants**, for "New Talents" and Senior/Junior researchers, to study original and interdisciplinary research topics;

2. **Research Projects**, including those defined as Strategic Projects, for the realization and promotion of interdisciplinary original research;

3. **Activities for the Dissemination of Scientific Culture and Historic Memory**, through the restoration of the “Monumental Complex” of Via Panisperna, the old Institute of Physics which has an extraordinary historical value, to be used in part for the Museum.
Strategic Research Projects

1. Extreme Energy Events (EEE) – Science inside Schools

2. Quark-Gluon Coloured World (QGCW) – ALICE and beyond

3. Advanced Techniques for Biomedical Applications

4. Energy

5. Environment and Cultural Heritage

6. Fundamental Physics, History of Physics & Complexity
Dissemination of Scientific Culture & Historic Memory

• Refurbishing of the historical building of the Institute of Physics (1880) at Via Panisperna in Rome started in 2010

• **Fermi Fountain** inaugurated as the 1\textsuperscript{st} Historic Site of the European Physical Society (EPS) in 2012 in the presence of the President of the Italian Republic Giorgio Napolitano
Fermi Fountain
1st Historic Site of the European Physical Society
April 2012
Fermi Museum

- MoUs established / to be established with:
  - Sapienza University (Rome)
  - Domus Galieiana (Pisa)
  - Fermilab (Chicago)
  - Fermi Institute, University of Chicago
  - Chicago Library

- MUSEO FERMI working group operative since early 2013

- Presentation of MUSEO FERMI Project in 2014

- Inauguration of MUSEO FERMI at Via Panisperna in … 2016 (??)

- Inauguration of *Fermi Exhibition* in 2015 on the occasion of IYL2015 and 90th anniversary of the discoveries that led Fermi to the Nobel Prize
Sezione dell'edificio di Via Panisperna, visto dal lato dell'ingresso al Centro Fermi, ossia dal lato del giardino dove si trova la storica fontana di Fermi.

Ipotesi di percorso museale in una parte del piano terreno della sede istituzionale del Centro Fermi.

L'edificio di Via Panisperna in fase di restauro (giugno 2015).
THE EEE – EXTREME ENERGY EVENTS PROJECT

SCIENCE INSIDE SCHOOLS
SCIENCE IN THE HEART OF THE YOUNG
A. ZICHICHI, Progetto “La Scienza nelle Scuole”
EEE – Extreme Energy Events
Società Italiana di Fisica (SIF), Bologna
1st Ed. 2004; 2nd Ed. 2005

 Collaboration project

Centro Fermi
CERN
INFN
MIUR
SIF

Launch event on 3 May 2004 at CERN

R. Aymar – CERN DG
L. Moratti – Minister of Science & Education
A. Zichichi – Centro Fermi President
Physics goal of EEE Project:
Detect atmospheric showers of very high / extreme energy by detecting secondary muons on ground coming from very high energy primary cosmic rays
It is indeed a physics experiment!

How?

By equipping a large number of Italian High Schools with a large EEE telescope:

a very sophisticated particle tracking detector with outstanding timing capabilities

→ The EEE Project has a dual role:

• **Education instrument** for students together with their tutors & teachers

• **Scientific instrument** for physicists which involves students in a forefront research experiment
The EEE Project

Since 2004 …

Pilot project with 7 EEE telescopes in High Schools (Bari, Bologna, Cagliari, Catania, Frascati, L’Aquila, Torino)

➔ In 2015: > 50 EEE telescopes
   42+5 in High Schools
   +5 in Labs

across an overall area of ≈ 0.5 x 10⁶ km²
At present, **47 High Schools** are involved:

42 + 5 new High Schools in 2015

They are mostly distributed in clusters in the whole Italian territory

+ 2 telescopes at CERN
+ 3 in INFN Units

Total: **52 telescopes**

⇒ 3 new High Schools in 2016 ⇒ 50 !!!

… 25 High Schools in waiting list !!!
After initial MIUR & INFN funding in 2004 → Extra MIUR funding in 2012-2013

• **Progetti Premiali 2012** (7% of FOE) for **2013-2014**
  - CF as PI (Principal Investigator) – 1 year
    - EEE (Extreme Energy Events) – An Italy-Wide Observatory of Cosmic Rays for Astrophysical Research and Advanced Scientific Training
    - CF with INFN

• **Progetti Premiali 2013** (7% of FOE) for **2014-2015**
  - CF – 1 year
    - EEE (Extreme Energy Events)
    - CF
New boost of the EEE Project thanks to the introduction of automatic – simultaneous – direct data transfer to INFN-CNAF computer centre

→ high statistics of cosmic muons
→ immediate data reconstruction & storage
EEE telescope with 3 MRPCs and relative system

Freon 98% / SF₆ 2%

Gas mixer

MRPC

FE Right

FE Left

-HV
+LV
-LV

Internet

USB Connected

DAQ

HV/LV Controller

INFN CNAF

GPS Receiver

VME CRATE
ALICE-TOF Multigap Resistive Plate Chamber (MRPC)

Cross section of double-stack MRPC

- Flat cable connector differential signal sent from strip to interface card
- Honeycomb panel (10 mm thick)
- PCB with cathode pickup pads
- External glass plates 0.55 mm thick
- Internal glass plates (0.4 mm thick)
- PCB with anode pickup pads
- Mylar film (250 micron thick)
- 5 gas gaps of 250 micron
- PCB with cathode pickup pads
- Honeycomb panel (10 mm thick)
- Silicon sealing compound
- M5 nylon screw to hold fishing-line spacer
- Connection to bring cathode signal to central read-out PCB

$C_2H_2F_4 \ 93\% \ / \ SF_6 \ 7\%$

Efficiency (%)

Time Resolution (ns)

NOVEMBER 2006 - HV Scan
The EEE telescope

MRPC chambers are built by High School students at CERN (starting from 2004) and maintained by them under the supervision of EEE researchers.

1 MRPC = 24 strips

~50 cm

Acceptance $\Omega = 1.6$ sr

Differential angular acceptance of Telescope

3 MRPC planes with 24 strips each read at both ends → 144 readout channels

- The trigger requires a hit signal on each end of the 3 MRPCs within a $\pm 500$ ns window
- Cosmic muons are tracked & reconstructed
EEE Project
MRPC construction
The EEE telescope

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3 MRPC planes with 24 strips each read at both ends $\rightarrow$ 144 readout channels

• The trigger requires a hit signal on each end of the 3 MRPCs within a $\pm 500 \text{ ns}$ window
• Cosmic muons are tracked & reconstructed
The time resolution of the MRPC is **better than 100 ps**, allowing to reconstruct the position along the strip with a precision of **0.84 cm**.
Efficiency vs. Noise

Efficiency ≈ 95%
Single MRPC rate < 20 KHz
Efficiency vs. Muon rate (3-MRPC coincidence rate)

Efficiency $\approx 95$

Muon rate $\approx 60$ Hz
EEE telescopes installed inside High Schools
The “event time” measurement

Each telescope is equipped with a **GPS** to measure the UTC time with very high precision (GPS resolution $\sim 100$ ns)

The GPS cannot provide directly a time when a **telescope trigger** signal is obtained

$\rightarrow$ The GPS provides a signal **once per second** and it **resets** a TDC counter which is devoted to count time (TDC bin $\sim 25$ ns) in between two GPS signals

$\rightarrow$ The TDC counts are **read & associated to the event** when the **telescope trigger** signal is obtained

The GPS time is crucial to study coincidences between **near and far** telescopes $\rightarrow$ extensive air showers $\rightarrow$ **extreme energy events**
The computing and data infrastructure to interconnect EEE telescopes

The Extreme Energy Event (EEE) experiment is devoted to the search of high-energy cosmic rays through a network of telescopes installed in about fifty high schools distributed throughout the Italian territory.

One of the main goals of the project is to involve young students in a high-level scientific enterprise.

Therefore the experiment is very peculiar and requires new solutions for the data management.

Data are collected (all Schools \(\rightarrow\) CNAF) and automatically reconstructed...
The EEE Project
2014 Pilot run &
2015 Run-1

• In 2014, a Pilot run involving the simultaneous and, for the first time, completely automatic acquisition and data storage of EEE events from half (23) of the EEE telescopes at the INFN CNAF computer centre of Bologna has been performed → Nearly 1 billion events i.e. muon tracks collected in nearly one month (27 October-14 November)

• In 2015, for Run-1, two thirds (35) of the EEE telescopes were ready to efficiently participate → Over 5 billion events i.e. muon tracks collected in about three months (2 February-30 April)
Data Transfers and Run-1 stats

- So far 35 telescopes connected to INFN CNAF and transferring data using bittorent sync
- A CNAF front-end is dedicated to receive all the data with a required bandwidth of 300 kB/s
- A btsync client is installed in each School (Win OS)
- 5-10 TB per year are expected
- Full statistics from Pilot run* to Run-1*: 
  - ~2.4 TB (raw: ~2 TB, reco: ~0.4 TB) corresponding to 
  - ~7 billion cosmic rays (+3 TB from past years)

*Pilot run from 27-10-2014 to 14-11-2014
Run-1 from 02-03-2015 to 30-04-2015

EEE monitor with information in real time https://www.cnaf.infn.it/eee/monitor/
Quasi online monitor

Extreme Energy Events Monitor

Run by run (50000 events)
quality monitor (real time)

Daily summary (trending infos available for analyses)

EEE DQM summary report

SUMMARY
- Station: CAGL-01
- Number of runs processed: 46
- Total number of events: 2094422
MRPC hits
Cosmic rays flux and EEE

EEE telescopes collect secondary muons coming from primary cosmic rays of over $10^{11}$ eV.

Coincidences between telescopes allow to select primary energies above $10^{15}$ eV (thousands of TeV).

Single telescope sensitivity
Multi-telescope analyses
High energy events

Increasing the distance between telescopes the energy of the primary observed increases as well. The flux of primaries depends on the energy, implying many days of operation needed for very large distances.
MC simulations for EEE telescopes

Coincidences expected per day between EEE telescopes as a function of the distance

→ Few months required to observe coincidences at 1 Km

Corsika MC simulations
First results in 2012 for coincidence events

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

Data from the following sites are included in the plot: CERN-Geneva (15 m), L’Aquila (180 m), Cagliari (520 m) and Frascati (650 m)

Consistent with Corsika & Cosmos MC simulations
As from 2014
– with more statistics
– taking advantage of the tracking capability of the telescopes to select different impact angles and apply angular & time corrections

→ the search for coincidence events from near and distant telescopes is successfully ongoing
Reconstruction of the primary cosmic ray direction

EEE telescopes allow to reconstruct the direction of the shower secondaries, i.e. of the shower axis

Such a feature allows to correct, event by event, the time delay between two telescopes because of the propagation of the wave front of the shower

This is very important when looking at coincidences at very large distances since above 1 Km the time delay may be of the order of few microseconds
Preliminary results from Run-1 (2015)

Coincidences were well reconstructed for several distances between telescopes (15 m, 100 m, 200 m, 500 m, 1200 m).

The width of the reconstructed peak is usually of the order of **200-250 ns** (CERN and Bologna cases differ because of particular GPS setups).
Preliminary results from Run-1 (2015)

For the **first time** coincidences were observed between two telescopes installed in High Schools at a **distance greater than 1 Km** (significance $S/\sqrt{S+B} = 5.1$)

The statistics used here includes also the data acquired in the Pilot run of 2014

⇒ One of the goals for next year is to extend such measurements to **larger distances** (up to 2 Km) and to extend the study to telescopes located in **different cities** to look for exotic (“unexpected”) high energy events
Among the non-periodic intensity variations, rapid decreases of the galactic cosmic-ray (GCR) flux due to solar activity (the so-called Forbush decreases) are the most common and the most interesting.

GCRD events consist of an impressive transient change in the cosmic-ray intensity.

They are characterized by a rapid (a few hours) intensity reduction, followed by a slow recovery in a few days time range.

Such strong variations are probably related to solar flares and the associated geomagnetic disturbances.
In 2012 a GCRD event observed by the Oulou (Finland) and Rome detectors of the Neutron Monitor Network, was also observed for the first time by 5 EEE telescopes: Altamura, Bologna (3), Catania
Galactic Cosmic Ray (GCR) flux variation due to solar activity

Unprecedented with muons in High Schools !!!
A recent GCRD

Muon rates averaged over 6 EEE telescopes and Neutron rates from the Oulu station, Finland, during the GCRD associated to X class solar flare on 7 November 2014

Immediately after the EEE Pilot run of **2014**, a GCRD event was observed by 6 EEE telescopes: Altamura, Frascati, Grosseto, Savona (2), Viareggio
A GCRD during this School!!

GCRD event observed by 5 EEE telescopes:
Bologna, Cagliari (2), Catania, CERN-Geneva
Few upgoing events are observed (1/2000) in EEE telescopes.

The nature of such events is under investigation.

A fraction of them can be clearly identified as electrons coming from muon decays (in the floor under the telescope), looking at their time correlation with previous events (∼ 2 μs).

Muon decay
Delayed
∼2μs

Upgoing electron delay of ∼ 2μs wrt parent Muon

DTp = time delay from previous event

Beta = v/c
Three-telescope coincidences

Coincidence studies will be extended also to the case of three telescopes

**Advantages**
- The energy of the primary is expected to be higher
- Background from accidental combinations is strongly suppressed

**Disadvantages**
- The rate expected is much lower than in the two-telescope case
  - more data taking needed
The lateral distributions of photons (open circles), electrons (open squares) and muons (open triangles) above 10 MeV energy and muons (stars) above 1 GeV simulated with Corsika MC.

Charged particles in addition to electrons and muons above 10 MeV energy are also plotted (full circles).

Below the distance indicated by the red arrows the muon density is expected to be larger than $1/m^2$.

→ multi-track events in single EEE telescopes could allow to select by telescope coincidences showers of even higher energy.
What next

- Increase the number of EEE telescopes from 50 to 100 High Schools (original project!)
- Increase the statistics of two-telescope coincidences and search for three-telescope coincidences within the same city
- Include multi-track telescope analysis in the search
- Search for coincidences of clusters of telescopes between different cities
- Search for upgoing events in single telescopes and in two-telescope coincidences
- Test the pointing capabilities of telescopes

⇒ SEARCH FOR THE UNEXPECTED …
The EEE Open Data Project

Tablets to 75 EEE High Schools (50 with + 25 without telescope) → Remote & continuous monitor of EEE telescopes and access to data even for Schools without telescopes

In collaboration with IPOGG (International Particle Physics Outreach Group) the EEE Project – Italy is participating in the newborn

GLOBAL HIGH SCHOOL COSMIC RAYS PROJECT

involving similar projects in Czech Republic, Denmark, France, Germany, Greece, The Netherlands, UK, USA and more
GLOBAL HIGH SCHOOL COSMIC RAYS PROJECT

• Establish a “universal” portal through which successful cosmic ray studies programs can reach out to teachers and students around the world

• This web portal would be the entry point for an international network of cosmic ray projects for education

• Students with a School detector could contribute data to a global project

• Students who are interested but without a detector could analyze data and/or participate in special events

→ magnified outreach potential for the EEE Project !!
THE EEE COLLABORATION
Thanks to those to whom I have borrowed/stolen slides

And thank you all for the attention
Primary cosmic proton of $10^{17}$ eV interacting at 15 km altitude → shower with $10^6$ muons on the city of Bologna
EEE Physics Publications until 2014

- Abbrescia M. et al. (EEE Collaboration), *The EEE experiment: cosmic rays, multigap resistive plate chambers and high school students*, XI Workshop on Resistive Plate Chambers and Related Detectors, PoS (RPC2012) 012