Search for long distance time correlations between cosmic air showers with the MRPC telescopes of the EEE network

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**Outline**

1. The EEE experiment
   - The detector
   - Current status
   - Recent upgrade

2. EEE experiment goals
   - Educational aspects
   - Physics program

3. Search for time correlations between telescopes

4. Conclusions
Network of **telescopes** based on Multi-gap Resistive Plate Chambers (MRPC) for the detection of cosmic ray muons installed in Italian high schools.

- Project started in 2004
- 56 telescopes at high schools
  + 2 telescopes at CERN
  + 4 at INFN Units
- Total: 62 telescopes
- + ≈ 50 institutes on the waiting list

[http://eee.centrofermi.it](http://eee.centrofermi.it)
The MRPC telescope

EEE station: telescope of 3 MRPC chambers (~ 80 x 160 cm²)

- Reasonable cost
- Long term operation required
- Efficiency close to 100%
- Reconstruction of muon orientation
- Good time resolution (TOF measurements)
The MRPC of the EEE Project

A larger (~ 1.5 m²) and simpler version of the MRPC developed for the ALICE TOF

- 6 gas gaps (spaced by 300 μm)
- C₂H₂F₄ (98%) and SF₆ (2%) continuously fluxed (2l/h)
- 24 readout copper strips laid out on both sides of the stack of glass plates
Performance of The EEE MRPCs

- Average time resolution $\sim 240$ ps
- Longitudinal spatial resolution $\sim 1.5$ cm
- Transverse spatial resolution $\sim 1$ cm
- Average efficiency of the telescopes $\sim 93\%$

Very good performance compatible with EEE requirements

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DATA TAKING AND UPGRADE

About 100 billion events collected since the start of organized data taking.

Upgrade plans:
- Recently built new 50 chambers (new telescopes and spares)
- New test protocol at CERN
- New 250 µm six-gap chambers (lower operating voltage, eco-friendly gas)
- Improved FE boards
- New trigger & GPS board
**Educational Aspects**

- The EEE telescopes are installed in Italian high schools
- High school students and teachers have built their own telescope at CERN and take care of the data taking
- Introducing high-school students and teachers to high energy physics
- Many activities organized or coordinated by Centro Fermi

More info: [https://eee.centrofermi.it/news](https://eee.centrofermi.it/news)
Examples of analyses carried out by the EEE Collaboration:

- Search for anisotropies of the secondary component
- Forbush decrease
- Upward going particles

**Detection of Extensive Air Showers**

- 2 or more telescopes in the same town
- Telescopes at distance > EAS extension

- Time Correlations between far telescopes
1. Long-distance time correlations between far telescopes

2. Coincidence events involving a large number of telescopes
1. Long-distance time correlations between far telescopes

2. Coincidence events involving a large number of telescopes
**Long distance correlations between far telescopes**

- Look for cosmic rays time correlations between detectors separated by distances larger than the extension of Extensive Air Showers.
- Possible physical mechanisms could justify the existence of LDC, all suggesting a “common history”:
  - EAS originating from cosmics emitted by the same source (limited by the presence of magnetic fields).
  - EAS originating from cosmics generated by the interaction of a primary cosmic with the interstellar medium.
  - EAS generated by the photodisintegration of primary cosmic rays in the solar field (GZ effect).
LDC: ANALYSIS STRATEGIES

RARE EVENTS → NEGLIGIBLE BACKGROUND NEEDED

Several analysis strategies adopted:

Correlations between telescope pairs (extensive air showers)

\[ R_{\text{spurious}} \approx 2 \times 0.04 \times 0.001 \times 10^{-3} = 8 \times 10^{-8} \text{ Hz} \quad \text{(typical values)} \]

- Analyzed coincidences between the 45 pairs of the 10 EEE cluster sites hosting at least two telescopes
- 3968 days of time exposure
- 96 observed events against 77.8 estimated background
- 5 candidate events with a p-value < 0.05

| Event | EEE pairs | Distance (km) | \(|t_1 - t_2|\) (µs) | \(\phi_{\text{incl}}\) (deg) | Expected events | p-value |
|-------|-----------|---------------|----------------------|-----------------------------|-----------------|---------|
| (A)   | BOLO-CAGL | 614           | 86                   | 27.1                        | 0.0009 ± 0.0002 | 0.007   |
| (B)   | BOLO-LAQ | 290          | 740                  | 0.1                         | 0.014 ± 0.001  | 0.014   |
| (C)   | CATA-TORI | 1040         | 88                   | 9.2                         | 0.0265 ± 0.0005| 0.026   |
| (D)   | GROS-TORI | 377           | 297                  | 14.1                        | 0.032 ± 0.001  | 0.031   |
| (E)   | CERN-CATA | 1200         | 248                  | 9.3                         | 0.049 ± 0.001  | 0.048   |

RARE EVENTS → NEGLIGIBLE BACKGROUND NEEDED

Several analysis strategies adopted:

Correlations between multi-track events in both telescopes

\[ R_{\text{spurious}} (2 \text{ tracks}) \approx 2 \times 0.02 \times 0.02 \times 10^{-3} = 8 \times 10^{-7} \text{ Hz} \]
Pre-selection of multi-track events:
- \( \text{Chi}^2 < 10 \)
- Parallelism constraint (scalar product with the seed track > 0.8)

Data set:
- No. of telescopes: 42 telescopes + 5 clusters
- No. of Events: 30 millions of coincident events (in +/- 2 seconds window)
- Period: 2013 → 2018

Analysis cuts:
- Telescope distance > 5 km
- Ntracks > 3 on both telescopes
Overall number of coincidences between EEE sites as a function of the time coincidence window, compared with the accidental coincidence background (in red).

Events excess observed for $\Delta T \approx 10^{-4}$ s

40 coincident events observed (expected background $\sim 23.4$ events)

p-value $\sim 10^{-3}$

Cuts optimization ongoing:
- Multi-tracks events selection (parallelism and quality)
- N. of tracks
- Site distance
- Relative angle
1. Long-distance time correlations between far telescopes

2. Coincidence events involving a large number of telescopes
Combined analysis of multi-telescope events
2. Combined analysis of multi-telescope events

Search for anomalous coincidence events involving a large number of EEE telescopes within ms time interval

No specific physical mechanism already known able to explain the existence of multi-particle correlations over a huge area

Underlying idea: Search for possible unexpected events

Strategy:

Consider all possible correlations between 2, 3, … N among N telescopes working and look for events outside the expected spurious rate

Compare results to expected spurious rate between N telescopes (not trivial)

Integrate over long data taking periods (> months)
Analysis details

- A nearly complete scan of all available statistics from RUN 5 (October 2018-June 2019, 244 days) carried out

- Extraction of the raw multiplicity spectrum (number of coincident events as a function of the number of telescopes)
PRELIMINARY RESULTS

- Highest multiplicity events observed: 5 events with 12 telescopes
- Roughly a factor 10 decrease in the yield for every additional telescope
Preliminary results

Comparison to the expected spurious rate

A reasonable agreement observed between raw data and spurious expected trend over 9 orders of magnitude.

An upper limit on the number of such events may be established.
CONCLUSIONS AND OUTLOOK

- Network continuously growing and successfully operating since 14 years
- Excellent performance in terms of time and spatial resolution and efficiency
- Coordinated data taking periods ongoing (100 billion tracks collected)
- Very interesting observations of cosmosics phenomena
- High school students strongly involved in the Project

Time correlations between far telescopes

- Different analysis approaches adopted
- Preliminary results extracted
- Next steps:
  - optimize the cuts
  - investigate the excess of events
  - increase the statistics
  - check the effect of various assumptions on the spurious rate (average number of telescopes, individual rates, efficiency,...)
  - repeat the analysis for multi-tracks
  - increase the statistics
THANK YOU FOR THE ATTENTION!
SPATIAL RESOLUTION

**Longitudinal spatial resolution** $\sigma_x$

RUN 2 $\sigma_x = 1.48 \pm 0.04$ cm  
RUN 3 $\sigma_x = 1.49 \pm 0.03$ cm

**Transverse spatial resolution** $\sigma_y$

RUN 2 $\sigma_y = 0.92 \pm 0.01$  
RUN 3 $\sigma_y = 0.92 \pm 0.01$
Test of eco-friendly gas mixture

Most promising configurations:

- R1234ze(50%) + CO₂ (50%)
- R1234ze(99%) + SF₆ (1%)
The number of the GZ event/year depends on:

- Primaries mass and energy
- Solar flux
- Photo-disintegration probability
- Solar magnetic field
- Detection array acceptance

Several numerical approaches:
Zatsepin, 1950; Gerasimova and Zatsepin, 1960; MedinaTanco and Watson, 1999; Epele et al., 1999; Fujiwara et al., 2006; Lafebre et al., 2008

Few GZ events expected per year

Observation of few candidates reported by the LAAS collaboration
Search for LDC with multi-track events

Several additional cuts investigated:
Effect of $\chi^2$
Several additional cuts investigated:
- Parallelism of the tracks
Search for LDC with multi-track events

Several additional cuts investigated:
Relative angle between EAS axis

Ratio w.r.t. random coincidences:
No significant differences seen with the relative angle
Expected average spurious rate for a specific combination of k telescopes

\[ R_{\text{spurious}} \sim N (R_{\text{single}})^k \times \Delta t^{k-1} \]

This should be multiplied by the number of possible combinations of k telescopes out of N working telescopes:

\[ P_{n,k} = \binom{n}{k} = \frac{n!}{k!(n-k)!} = \frac{1}{k!} \prod_{i=0}^{k-1} (n - i) \]
Number of possible combination of telescopes out of 30 working
Preliminary results

Comparison to the expected spurious rate

Assumptions:
- Individual incoming muon rate
- Detection efficiency
- Number of working telescopes/day
Assumed: 30 working telescopes
Average single rate from all telescopes: 29 Hz
Efficiency to be take into account