Extreme Energy Events
Science inside Schools

SEARCH FOR COINCIDENT AIR SHOWERS OVER LARGE SCALE DISTANCES WITH THE EEE NETWORK

Paola La Rocca*

on behalf of the EEE Collaboration

* Museo storico della Fisica e Centro Studi e Ricerche Enrico Fermi
Department of Physics and INFN Section of Catania

OUTLINE

- ✓ The EEE experiment
  - The detector
  - Current status
  - Upgrade plans
- ✓ EEE experiment goals
  - Educational aspects
  - Physics program
- ✓ LDC events search
- ✓ Conclusions

THE EXTREME ENERGY EVENTS PROJECT

http://eee.centrofermi.it

EEE experiment: a network of telescopes based on Multi-gap Resistive Plate Chambers for the detection of cosmic ray muons installed in Italian high schools.

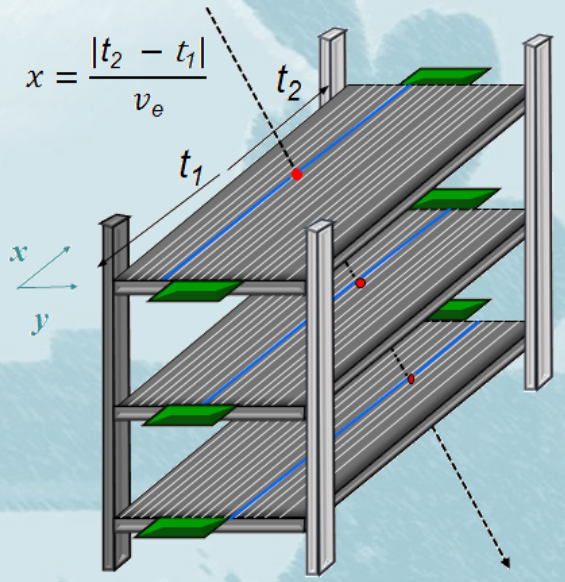
- ✓ Project started in 2004
- ✓ 50 telescopes at high schools
  + 2 telescopes at CERN
  + 4 at INFN Units
  Total: 56 telescopes
  + ≈ 50 institutes on the waiting list

Extreme Energy Events
Science inside Schools

THE MRPC TELESCOPE

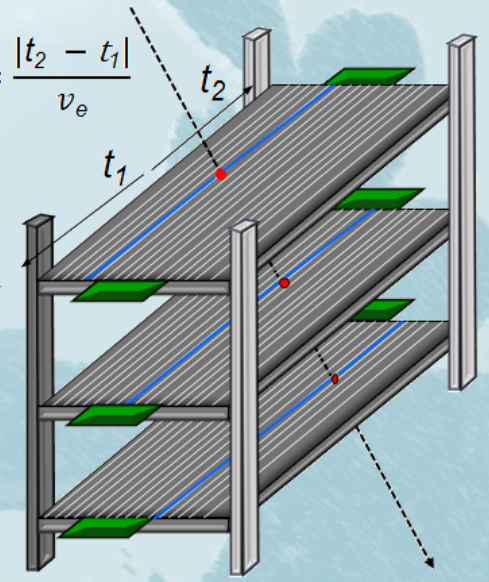
EEE station: telescope of 3 MRPC chambers (~ 80 x 160 cm^2)

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



Extreme Energy Events
Science inside Schools

THE MRPC TELESCOPE

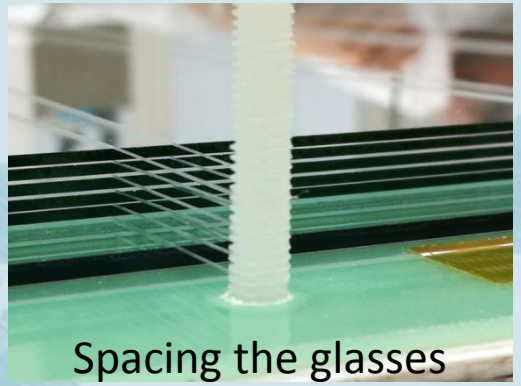


Extreme Energy Events
Science inside Schools

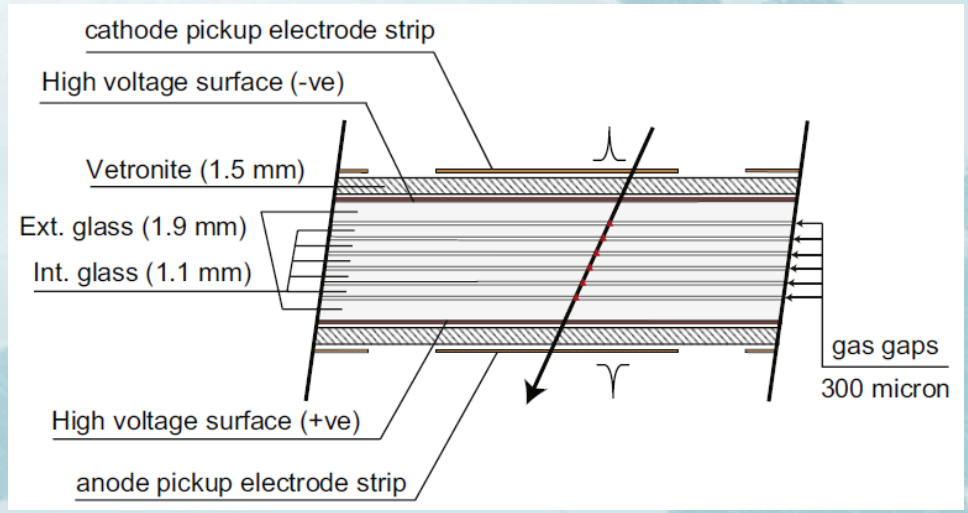
THE EEE MULTIGAP RESISTIVE PLATE CHAMBER

It is a larger (~ 2 m^2) 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)

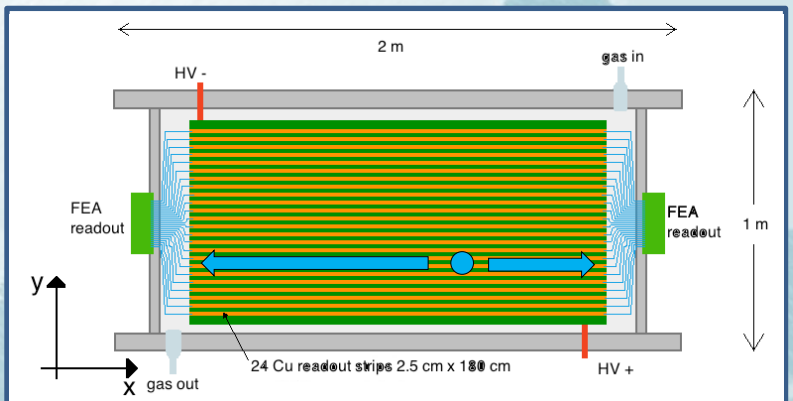


Spacing the glasses



THE EEE MULTIGAP RESISTIVE PLATE CHAMBER

- ✓ 24 readout copper strips laid out on both sides of the stack of glass plates
- ✓ Strip pitch 3.2 cm



x coordinate: difference of signal arrival times at the strip ends measured by TDCs
y coordinate: fired strip

THE EEE MULTIGAP RESISTIVE PLATE CHAMBER

Telescope equipment:

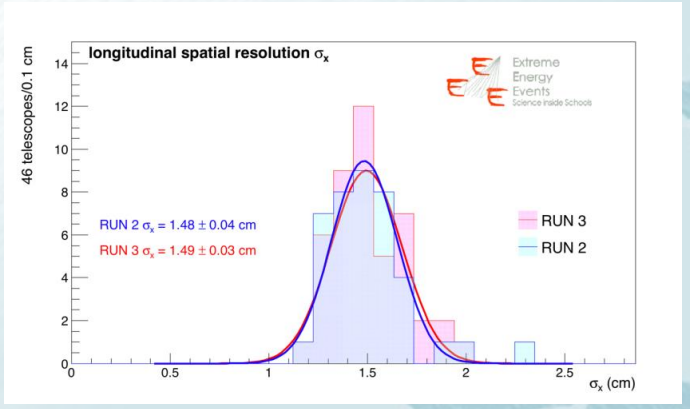
- ✓ 6 FE cards (with NINO chips) for readout and trigger
- ✓ VME-based data acquisition (Trigger card + Multi-hit TDCs)
- ✓ DC/DC converters for HV (±10 kV) to chambers
- ✓ GPS time-stamp of the collected events
- ✓ Weather Station

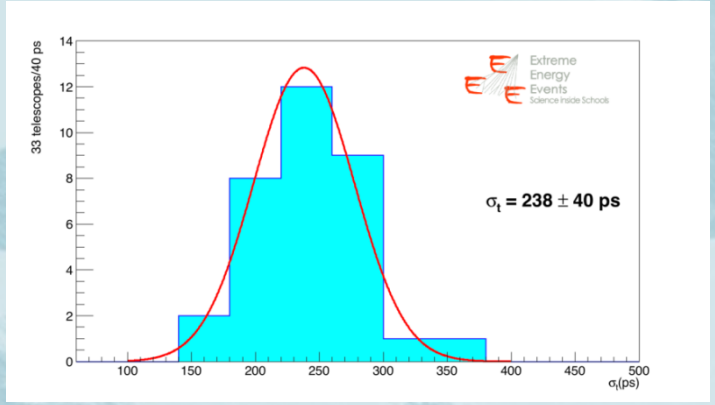
PERFORMANCE OF THE EEE MRPCS

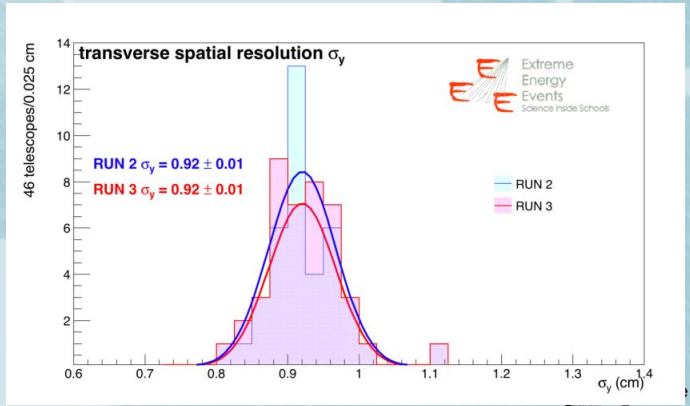
Time and spatial resolution of the chambers evaluated on a sub-set of telescopes:

- ✓ Average Time Resolution ~ 240 ps
- ✓ Longitudinal Spatial Resolution ~ 1.5 cm
- ✓ Transverse Spatial Resolution ~ 1 cm

Very good performance compatible with EEE requirements

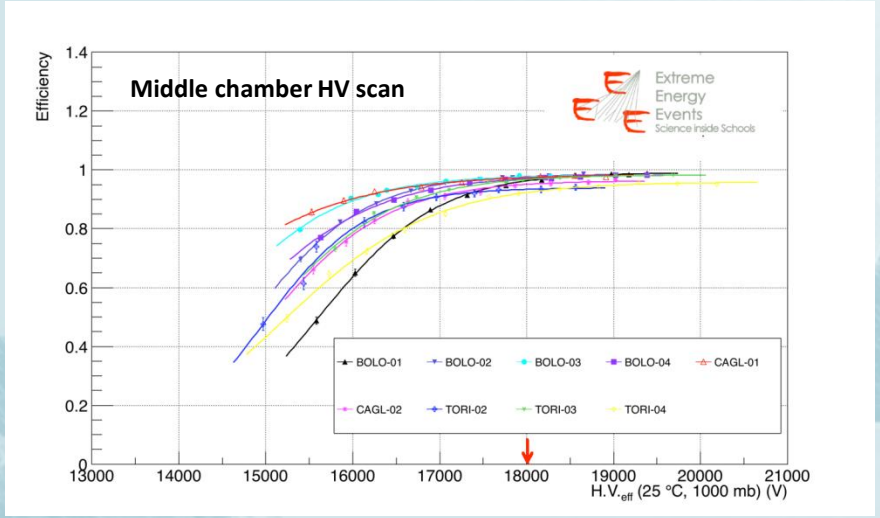


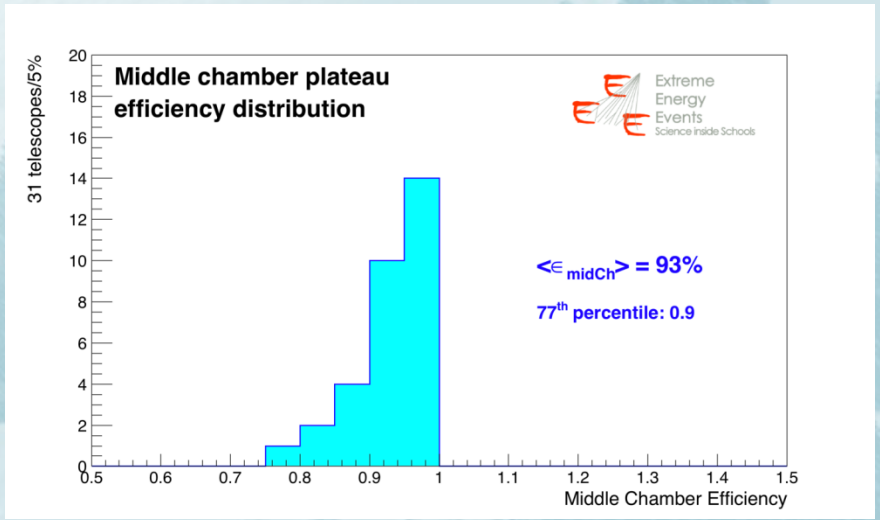




PERFORMANCE OF THE EEE MRPCS

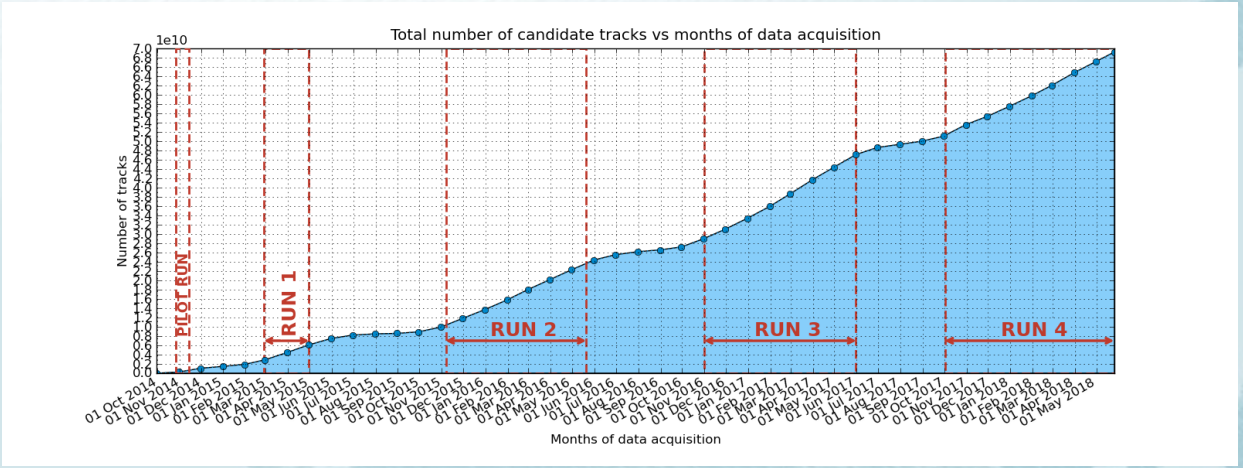
- ✓ Chamber efficiency evaluated on a sub-set of telescopes
- ✓ HV scan performed on the middle chamber during data-taking
- ✓ Average efficiency of the telescope network ~93 %





THE EEE NETWORK UPGRADE

About **70 billion** events collected since the start of organized data taking

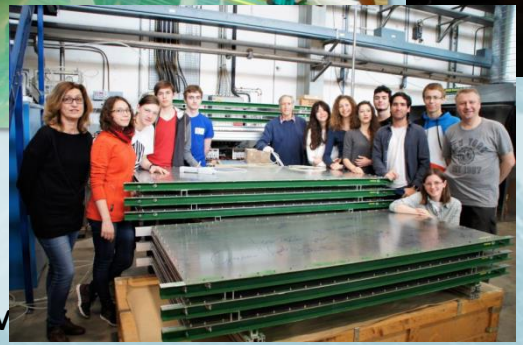


Upgrade plans:

- ✓Build new 20 telescopes
- ✓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

Extreme Energy Events
Science inside Schools

PHYSICS GOALS

Examples of analyses carried out by the EEE Collaboration:

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

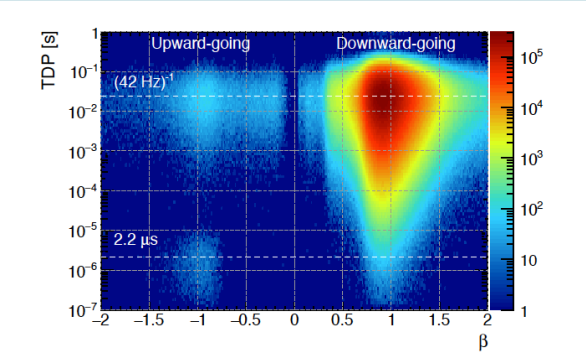
single telescopes

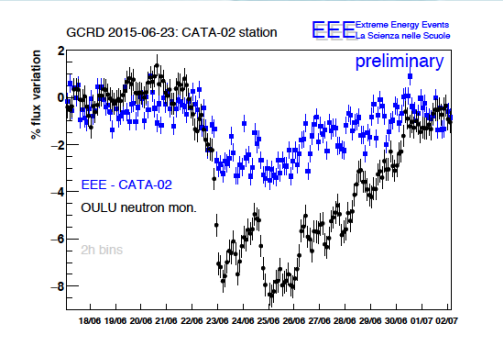
- ✓ Detection of Extensive Air Showers

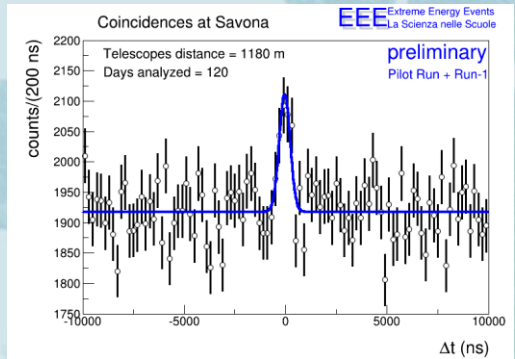
2 or more telescopes in the same town

- ✓ Long Distance Correlations (LDC)

telescopes at distance > EAS extension



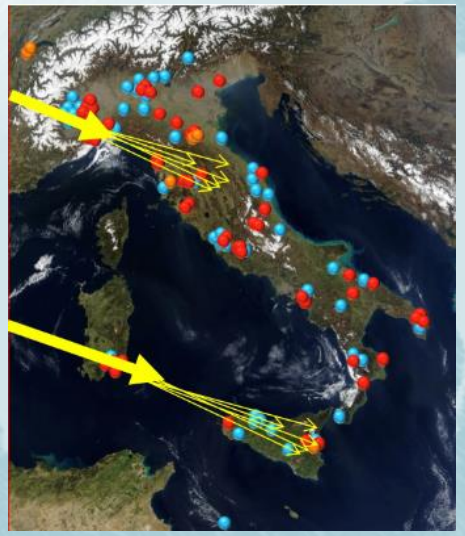




Extreme Energy Events
Science inside Schools

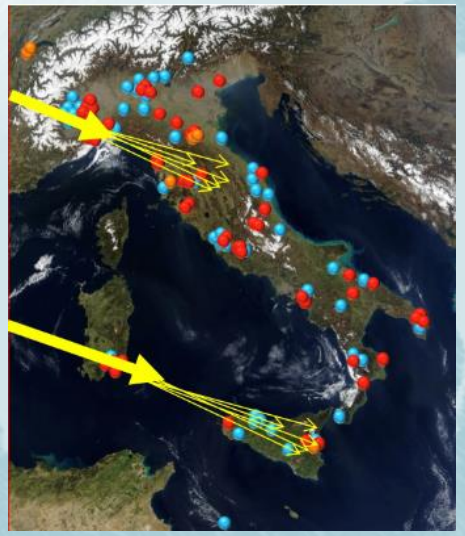
LDC: THE PROBLEM

- ✓ 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: THE PROBLEM

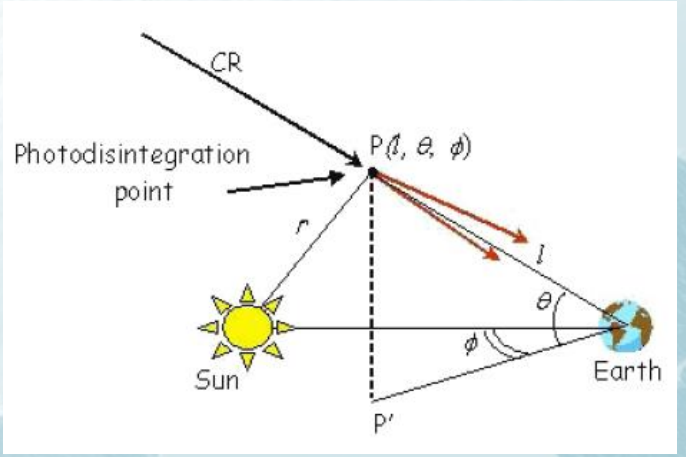
- ✓ Look for cosmic rays time correlations between detectors separated by distances larger than the extension of Extensive Air Showers
- ✓ Possible physical mechanisms could justify the existence of LDC, all suggesting a “common history”
  - EAS originating from cosmics emitted by the same source (limited 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)



THE GZ EFFECT

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

ANALYSIS STRATEGIES WITH EEE TELESCOPES

RARE EVENTS → NEGLIGIBLE BACKGROUND NEEDED

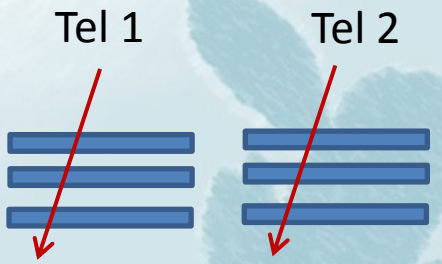
- ✓ **Correlations between independent telescopes**
  (single track events)
  $R_{spurious} \approx 2 \times 20 \times 20 \times 10^{-3} = 0.8$ Hz

- ✓ **Correlations between telescope pairs**
  (extensive air showers)
  $R_{spurious} \approx 2 \times 0.04 \times 0.001 \times 10^{-3} = 8 \cdot 10^{-8}$ Hz (typical values)

- ✓ **Correlations between multi-track events in both telescopes**
  $R_{spurious}$ (2 tracks) $\approx 2 \times 0.02 \times 0.02 \times 10^{-3} = 8 \cdot 10^{-7}$ Hz

ANALYSIS STRATEGIES WITH EEE TELESCOPES

RARE EVENTS → NEGLIGIBLE BACKGROUND NEEDED



✓ **Correlations between independent telescopes**
(single track events)

$R_{spurious} \approx 2 \times 20 \times 20 \times 10^{-3} = 0.8$ Hz

✓ **Correlations between telescope pairs (extensive air showers)**

$R_{spurious} \approx 2 \times 0.04 \times 0.001 \times 10^{-3} = 8 \cdot 10^{-8}$ Hz (typical values)

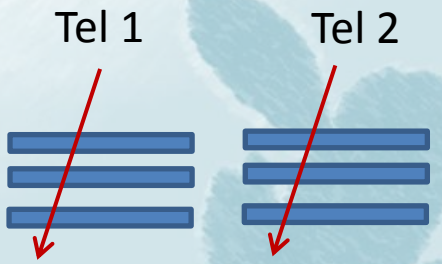
✓ **Correlations between multi-track events in both telescopes**

$R_{spurious}$ (2 tracks) $\approx 2 \times 0.02 \times 0.02 \times 10^{-3} = 8 \cdot 10^{-7}$ Hz

Extreme Energy Events
Science inside Schools

ANALYSIS STRATEGIES WITH EEE TELESCOPES

RARE EVENTS → NEGLIGIBLE BACKGROUND NEEDED



~~✓ **Correlations between independent telescopes**~~
~~(single track events)~~
~~$R_{spurious} \approx 2 \times 20 \times 20 \times 10^{-3} = 0.8$ Hz~~

✓ **Correlations between telescope pairs (extensive air showers)**

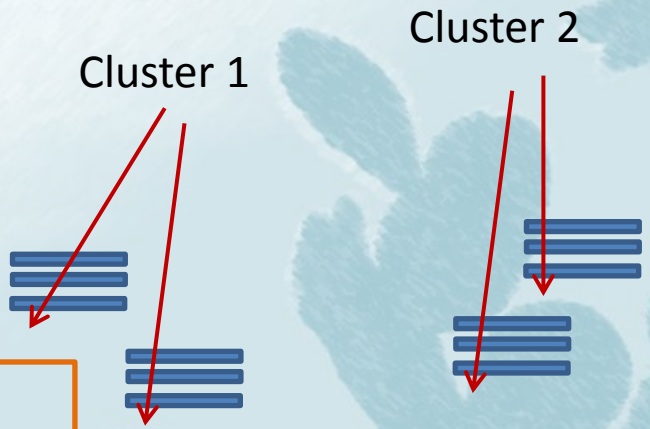
$R_{spurious} \approx 2 \times 0.04 \times 0.001 \times 10^{-3} = 8 \cdot 10^{-8}$ Hz (typical values)

✓ **Correlations between multi-track events in both telescopes**

$R_{spurious}$ (2 tracks) $\approx 2 \times 0.02 \times 0.02 \times 10^{-3} = 8 \cdot 10^{-7}$ Hz

ANALYSIS STRATEGIES WITH EEE TELESCOPES

RARE EVENTS → NEGLIGIBLE BACKGROUND NEEDED



✓ **Correlations between independent telescopes**
(single track events)

$R_{spurious} \approx 2 \times 20 \times 20 \times 10^{-3} = 0.8$ Hz

✓ **Correlations between telescope pairs**
(extensive air showers)

$R_{spurious} \approx 2 \times 0.04 \times 0.001 \times 10^{-3} = 8 \cdot 10^{-8}$ Hz (typical values)

✓ **Correlations between multi-track events in both telescopes**

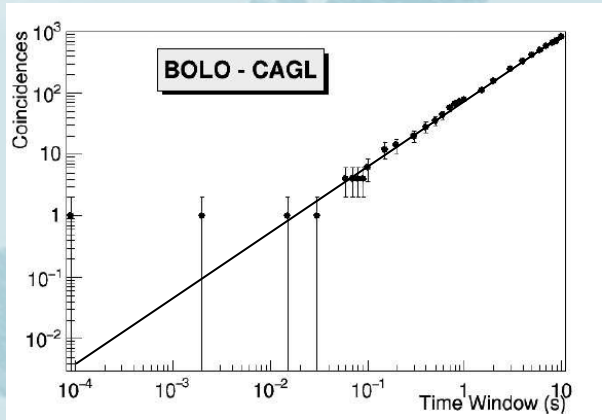
$R_{spurious}$ (2 tracks) $\approx 2 \times 0.02 \times 0.02 \times 10^{-3} = 8 \cdot 10^{-7}$ Hz

Extreme Energy Events
Science inside Schools

CORRELATIONS BETWEEN TELESCOPE PAIRS

- ✓ 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)	$\lvert t_1 - t_2 \rvert$ (μs)	$\vartheta_{\rm rel}$ (deg)	Expected events	p-value
(A)	BOLO-CAGL	614	86	27.1	0.0069 ± 0.0002	0.007
(B)	BOLO-LAQU	290	740	9.1	0.014 ± 0.001	0.014
(C)	CATA-TORI	1040	88	9.2	0.0265 ± 0.0005	0.026
(D)	GROS-TORI	377	297	14.4	0.032 ± 0.001	0.031
(E)	CERN-CATA	1200	248	9.3	0.049 ± 0.001	0.048



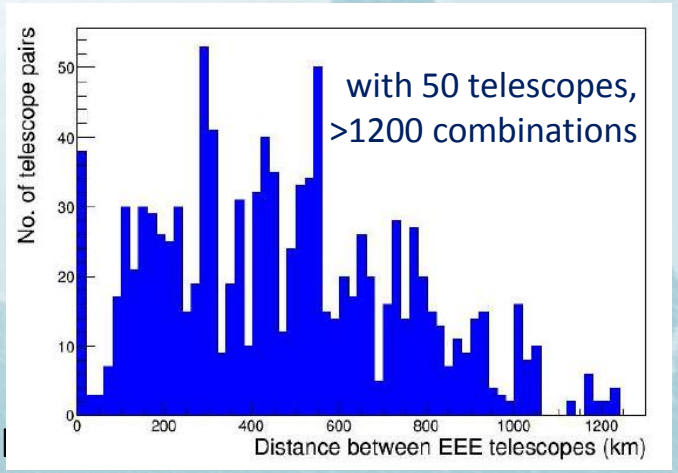
Eur. Phys. J. Plus (2018) 133: 34

ANALYSIS STRATEGIES WITH EEE TELESCOPES

RARE EVENTS → NEGLIGIBLE BACKGROUND NEEDED

- ✓ **Correlations between independent telescopes**
  (single track events)
  $R_{spurious} \approx 2 \times 20 \times 20 \times 10^{-3} = 0.8$ Hz

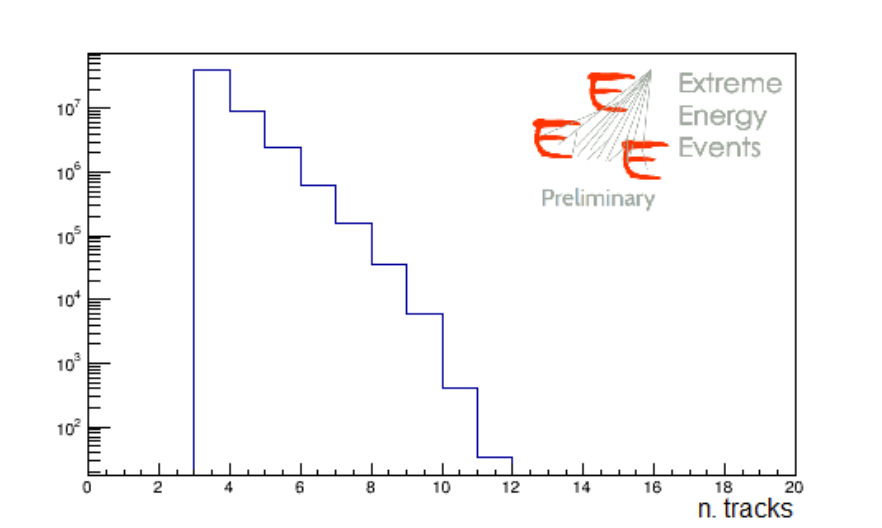
- ✓ **Correlations between telescope pairs**
  (extensive air showers)
  $R_{spurious} \approx 2 \times 0.04 \times 0.001 \times 10^{-3} = 8 \cdot 10^{-8}$ Hz (typical val

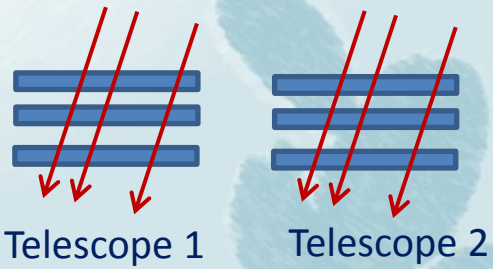


- ✓ **Correlations between multi-track events in both telescopes**
  $R_{spurious}$ (2 tracks) $\approx 2 \times 0.02 \times 0.02 \times 10^{-3} = 8 \cdot 10^{-7}$ Hz

ALTERNATIVE STRATEGIES: MULTI-TRACK EVENTS

Distribution of the number of tracks per event





Selection of multi-track events:

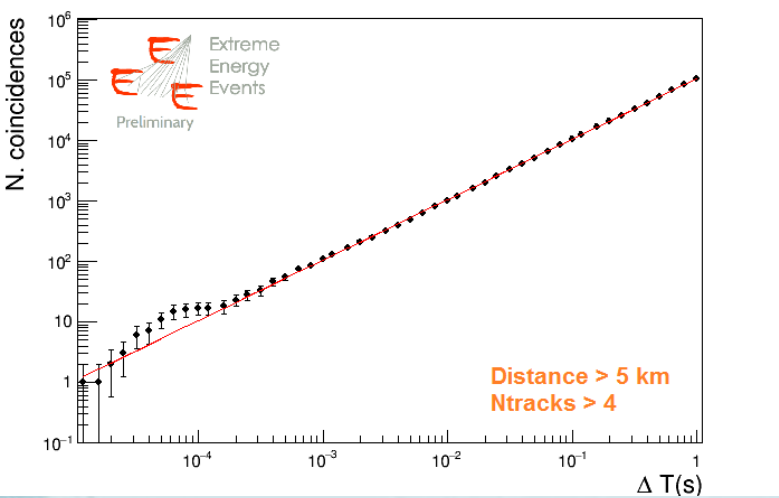
- ✓ Chi2 < 50
- ✓ Parallelism constrain (scalar product with the seed track > 0.8)

→ Cuts to be optimized

ALTERNATIVE STRATEGIES: MULTI-TRACK EVENTS

Data-set description

No. of telescopes: 39 telescopes + 5 clusters
No. of Events: 50 millions of events
Period: 2016-01-01 → 2018-03-26 (RUN2 + RUN3 + RUN4) = 816 days

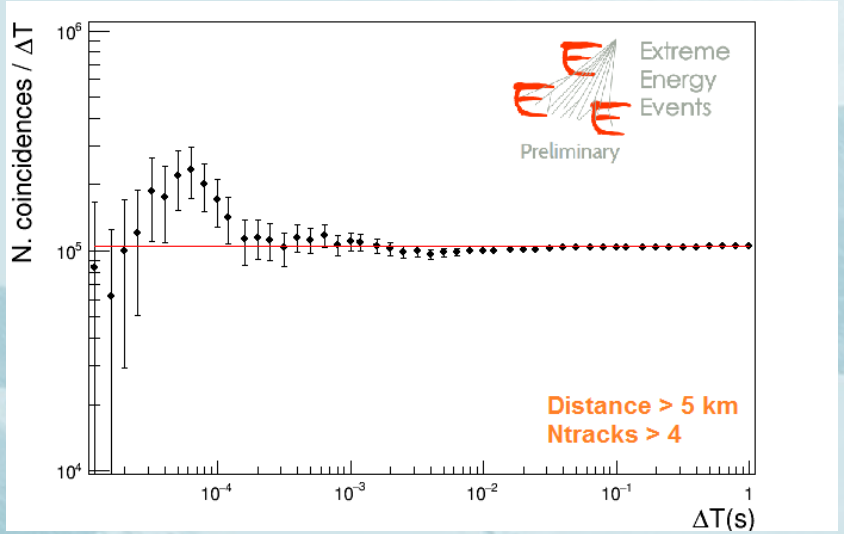


Overall number of coincidences between EEE sites as a function of the time coincidence window, compared with the accidental coincidence background (in red)

ALTERNATIVE STRATEGIES: MULTI-TRACK EVENTS

Data-set description

No. of telescopes: 39 telescopes + 5 clusters
No. of Events: 50 millions of events
Period: 2016-01-01 → 2018-03-26 (RUN2 + RUN3 + RUN4) = 816 days



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

Cuts optimization ongoing:
- Multi-tracks events selection
- N. of tracks
- Site distance
- Relative angle

CONCLUSIONS

- ✓ 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 (70 billion tracks collected)
- ✓ Very interesting observations of cosmics phenomena
- ✓ High school students strongly involved in the Project

Long Distance Correlations

- ✓ Possible candidate events observed
- ✓ Analysis still ongoing (cuts optimization and study of the multi-tracks events topology)
- ✓ Waiting for new statistics
  - new sites entering into their operational stage (2 of them testing new eco-friendly mixtures)
  - larger efficiency and duty cycle
  - new campaign measurements

THANK YOU FOR your ATTENTION! ANY QUESTIONS?

Extreme Energy Events
Science inside Schools