CENTRO RICERCHE ENRICO FERMI

Extreme Energy Events
Science inside Schools

DIPARTIMENTO DI FISICA E ASTRONOMIA "ETTORE MAJORANA"

INFN
Istituto Nazionale di Fisica Nucleare

Looking for long-range correlations among the EEE telescopes

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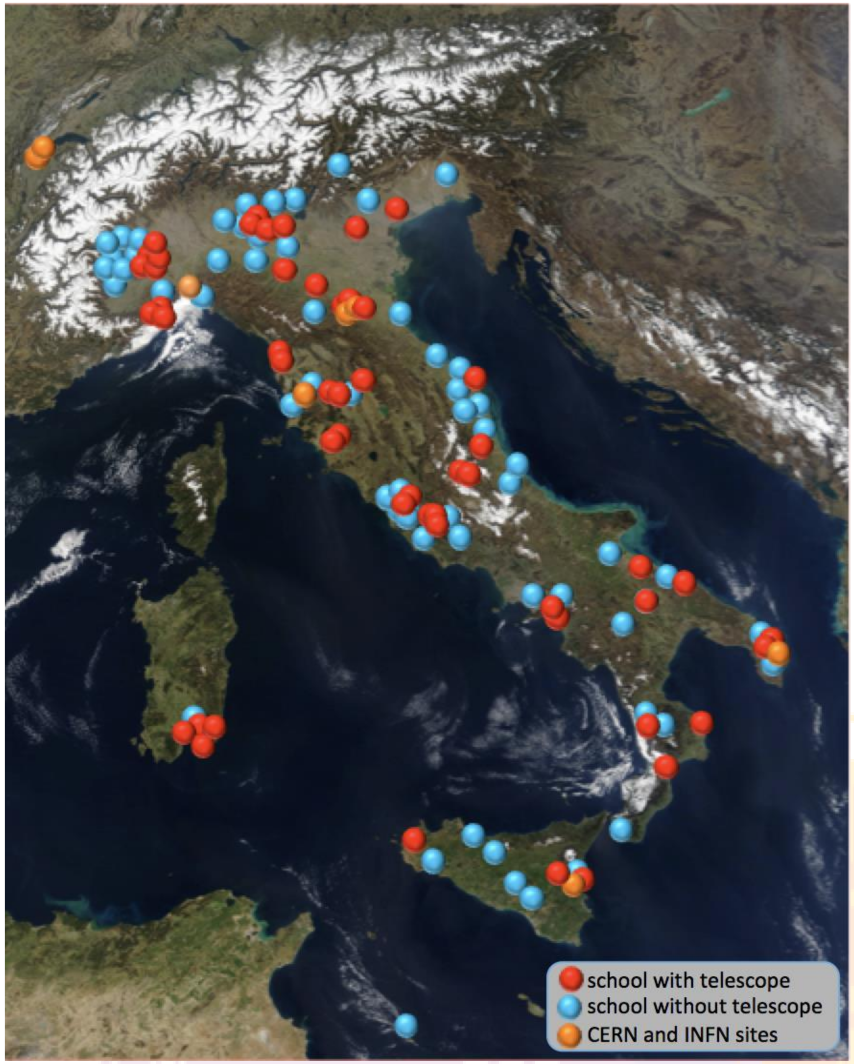
University of Catania and INFN Sect. of Catania

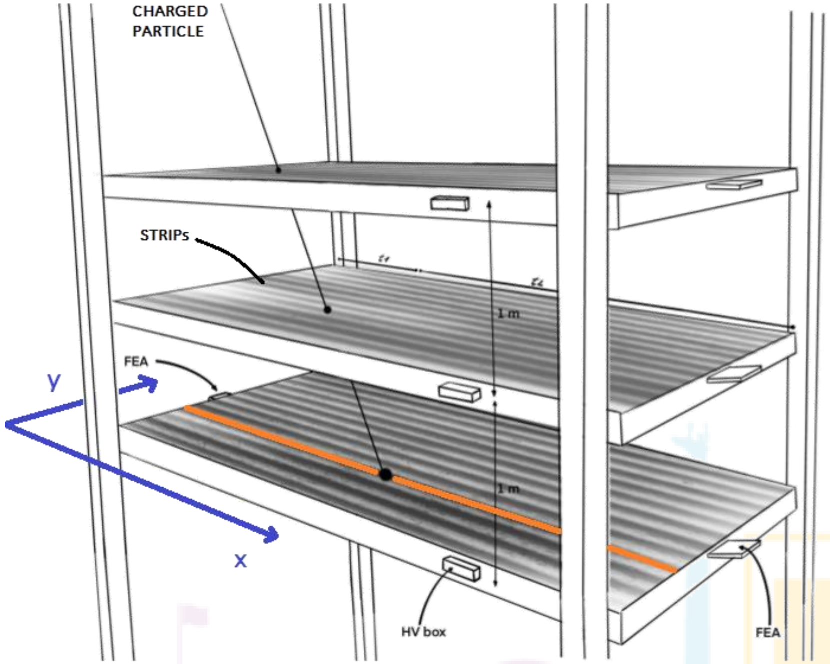
The Extreme Energy Events (EEE) experiment



Web site: eee.centrofermi.it

- Network of telescopes based on Multi-gap Resistive Plate Chambers (MRPC)
- Main goal: build an extensive sparse array of detectors for the study of secondary CR
- Telescopes installed in Italian high schools, INFN/Centro Fermi and CERN
- Total: ~ 60 telescopes + ~ 50 high schools on the waiting list

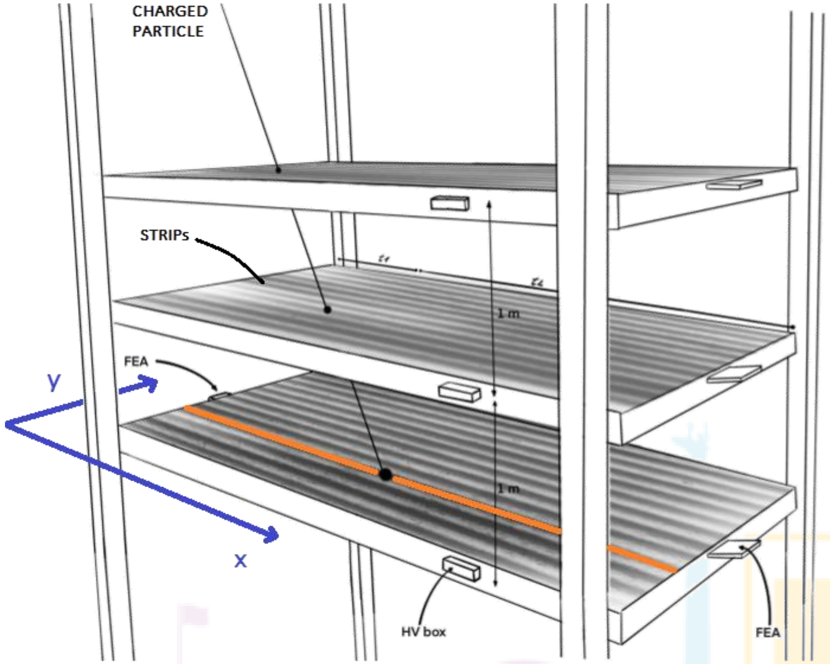
The EEE telescopes



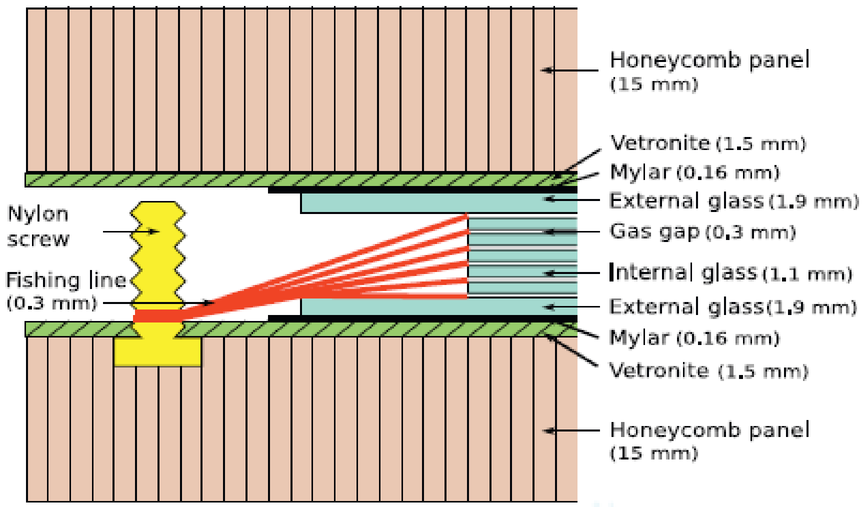
Telescope: 3 MRPCs (~ 160 x 80 cm^2)

- Built by students at CERN
- Reasonable cost
- Long term operation required
- High detection efficiency
- Reconstruction of muon orientation
- Good time resolution (TOF measurements)
- GPS for the synchronization between telescopes

The EEE telescopes

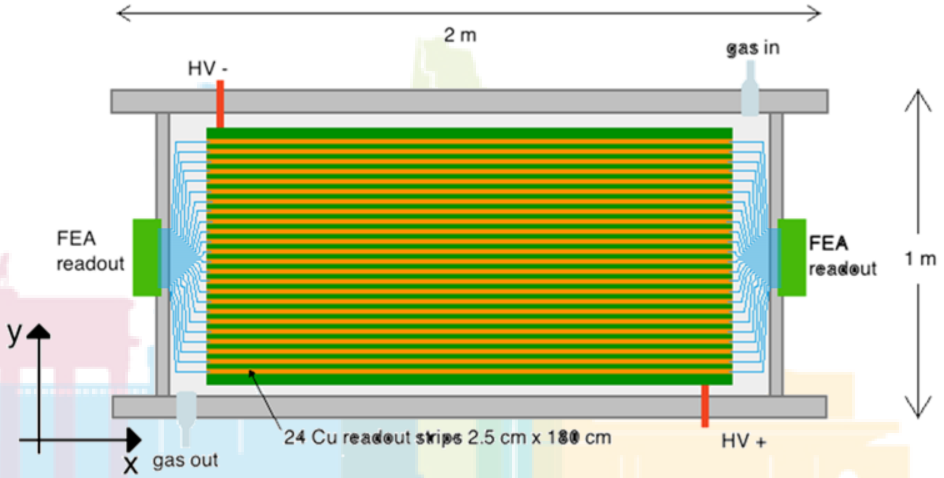


The EEE MRPCs



Specifications:

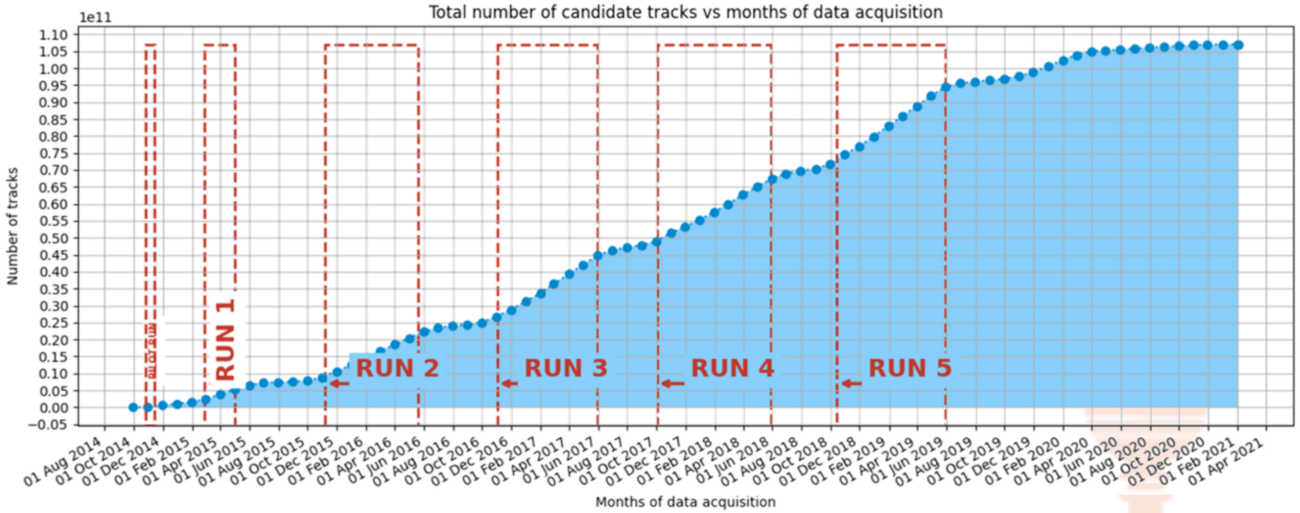
- 6 gas gaps (spaced by 300 µm)
- $C_2H_2F_4$(98%) and SF_6(2%) continuously fluxed (2l/h)
- 24 readout copper strips laid out on both sides of the stack of glass plates
- Operating HV $\pm$ 10 kV



Performance of the chambers:

- Average time resolution ~ 240 ps
- Longitudinal spatial resolution ~ 1.5 cm
- Transverse spatial resolution ~ 1 cm
- Average efficiency of the chambers > 90 %

Data taking and upgrade



The EEE network is the largest and long-living MRPC-based telescopes array

- ~ 17 years of operation
- About 100 billion events collected
- In 2020-21 slowdown due to COVID
- The network grown up by a factor ~ 8 in terms of number of telescopes w.r.t. 2007

Upgrade program started in 2017

- Built 50 additional chambers with new gas gaps (250 μm) and lower operating voltage
- New eco-friendly gas mixtures and reduced gas flow tested
- New trigger & GPS board

Physics program

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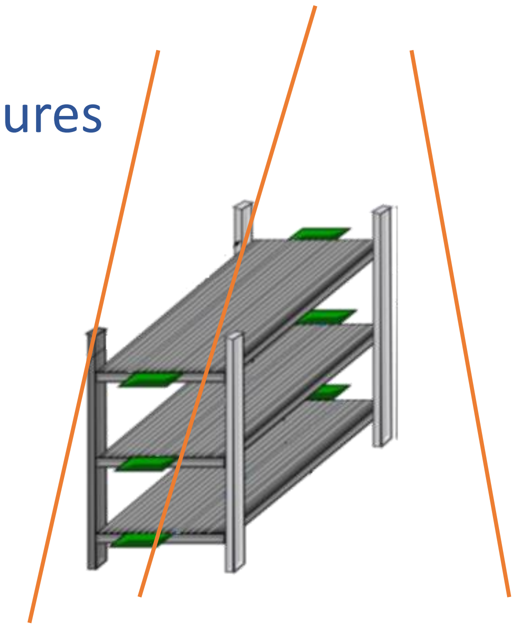
What can be done employing:

- **Single telescopes**
  - Measure of the local cosmic ray flux and its space weather-correlated features
  - Anisotropies in the muon angular distribution
  - Phenomena related with the upward-going particle flux



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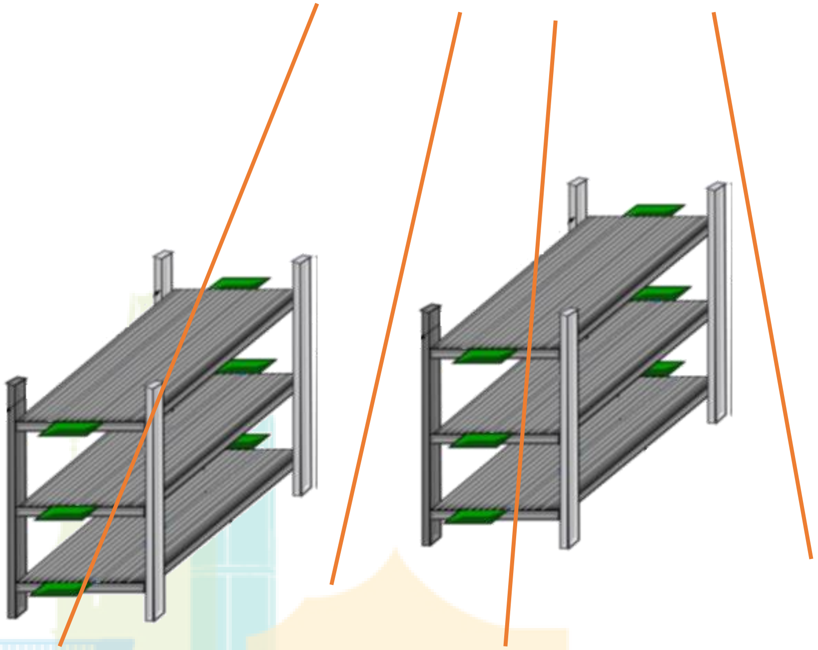
- **2 or more telescopes in the same metropolitan area**
  - Detection of extensive air showers



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- **Far telescopes (distance > EAS extension)**
  - Coincidence events involving a large number telescopes
  - Long-range time correlation between far telescopes

Physics program

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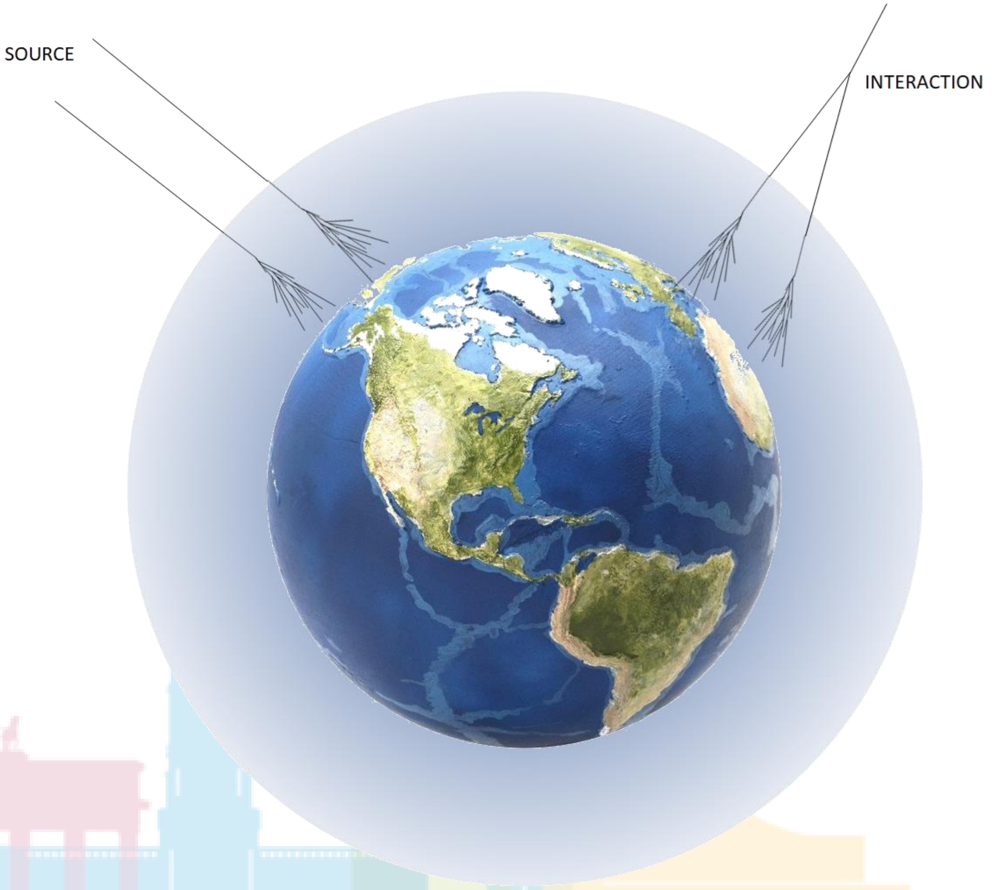
Long-range correlations between EASs

Mechanisms which are able to explain the existence of correlated EAS at large distances:

- Two primary cosmics, originating from the same source
- Single primary interacting with the interstellar medium and/or the radiation field and producing two intermediate products

Leading example: Gerasimova-Zatsepin (GZ) effect, i.e. photodisintegration of primary cosmic rays in the solar field



Long-range correlations between EASs

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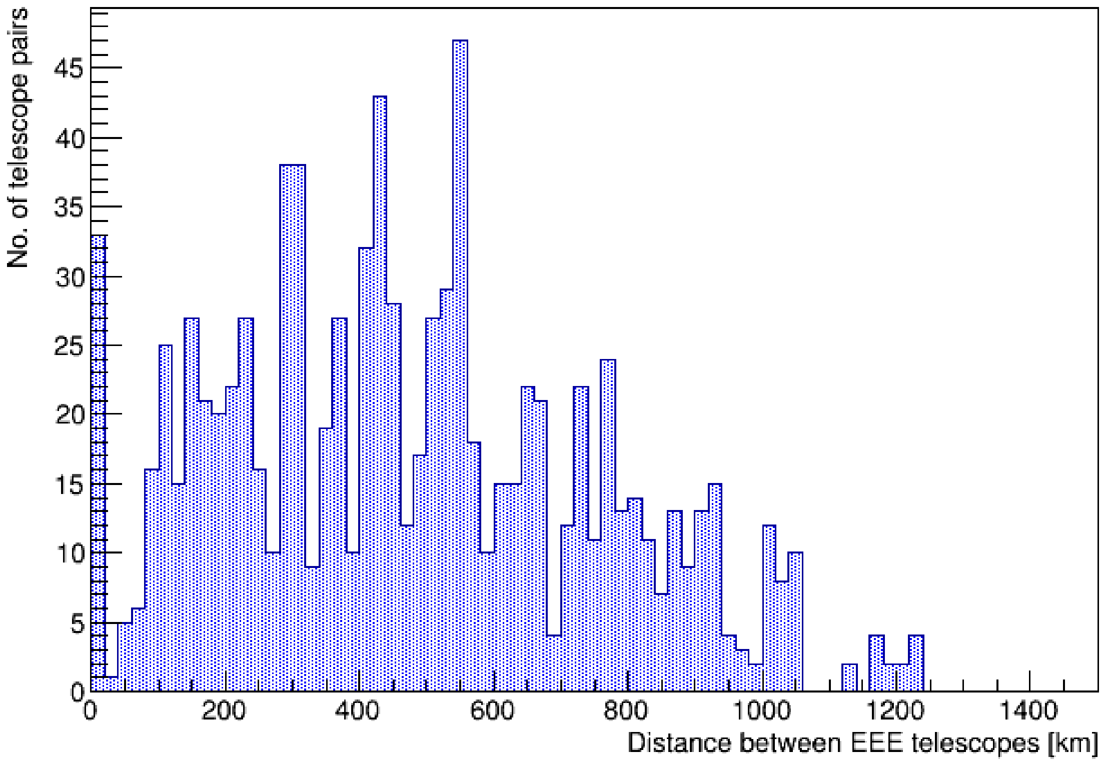
Distribution of the separation distance between all possible pairs of EEE telescopes

Distances between telescopes ranges from 15 m up to 1200 km



Analysis strategy

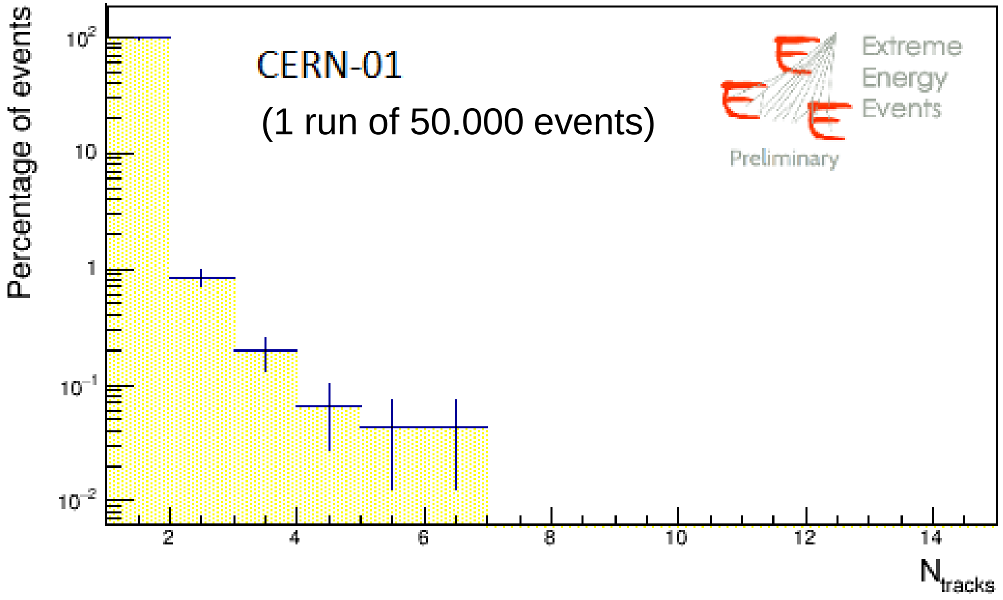
Challenging analysis:

- Extremely rare phenomenon
- Huge statistics is necessary
- Negligible background (spurious coincidences) is needed

→ Need of a pure sample of EAS events

- Evaluated several strategies
- **Look for time correlations between multi-track events in far telescopes**

Multi-track events correspond to a few percent of the collected events



Spurious coincidences between 2 telescopes (each detecting 3 tracks) in 1 ms:

$R_{spurious}$ (3 tracks) ~ 2 x 0.02 x 0.02 x 10^{-3} = 8 x 10^{-7} Hz

Data set and quality cuts

Data set:

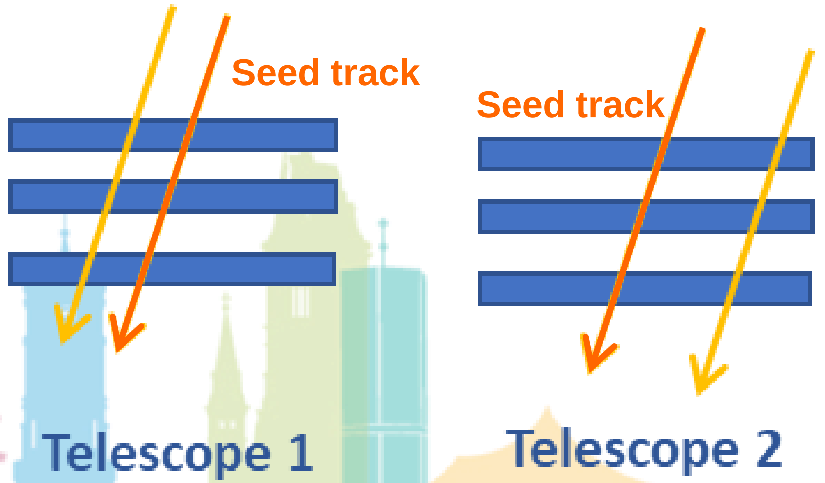
- Full available statistics: 2015-2020
- All EEE telescopes (no clusters)

Info available:

- Telescope codes
- Event time
- Direction, position and $\chi 2$ of individual tracks
- Sum of the scalar products between each track and the seed track (measure of the alignment between tracks in the same telescope)

Preselection cuts:

- $\chi 2 < 10$
- Scalar product (track - seed track) > 0.8
- Distance between telescopes > 5 km

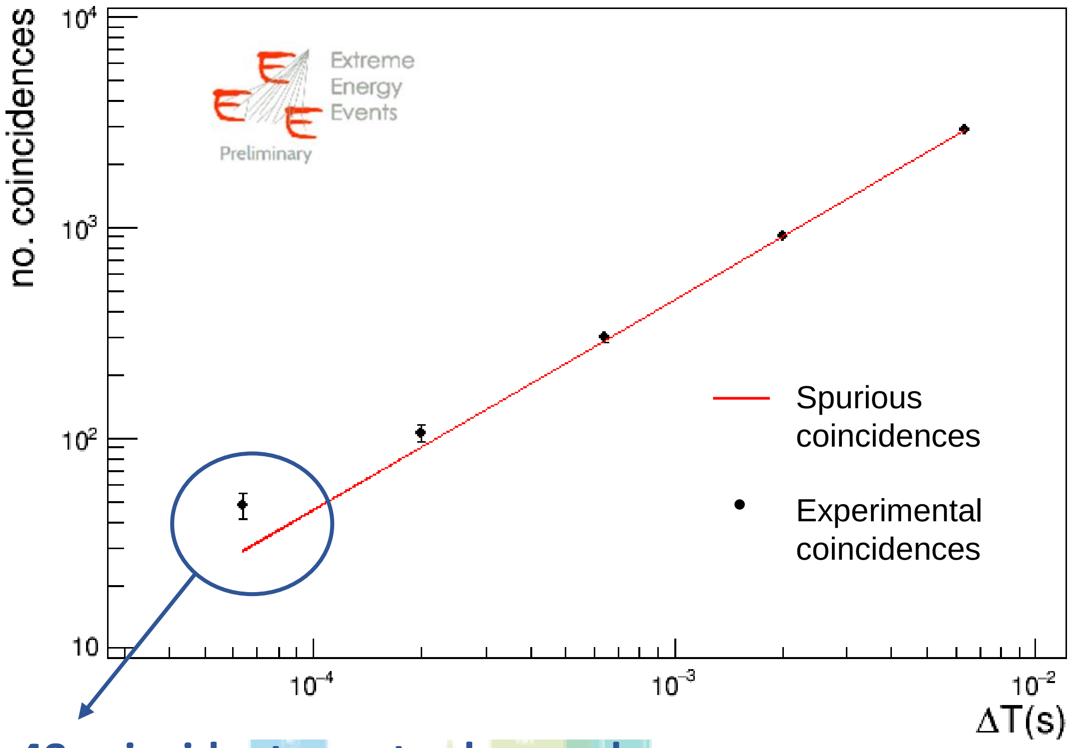


Preliminary results

The number of coincidences between all pairs of EEE telescopes was studied as a function of:

- coincidence time window (down to $\pm 10^{-5}$ s)
- cuts on sites distance, no. of tracks, $\chi 2$, parallelism of the tracks in each telescope

Background due to spurious coincidences:
no. of coincidences in $\pm$ 1 s scaled by a factor equal to the coincidence time window

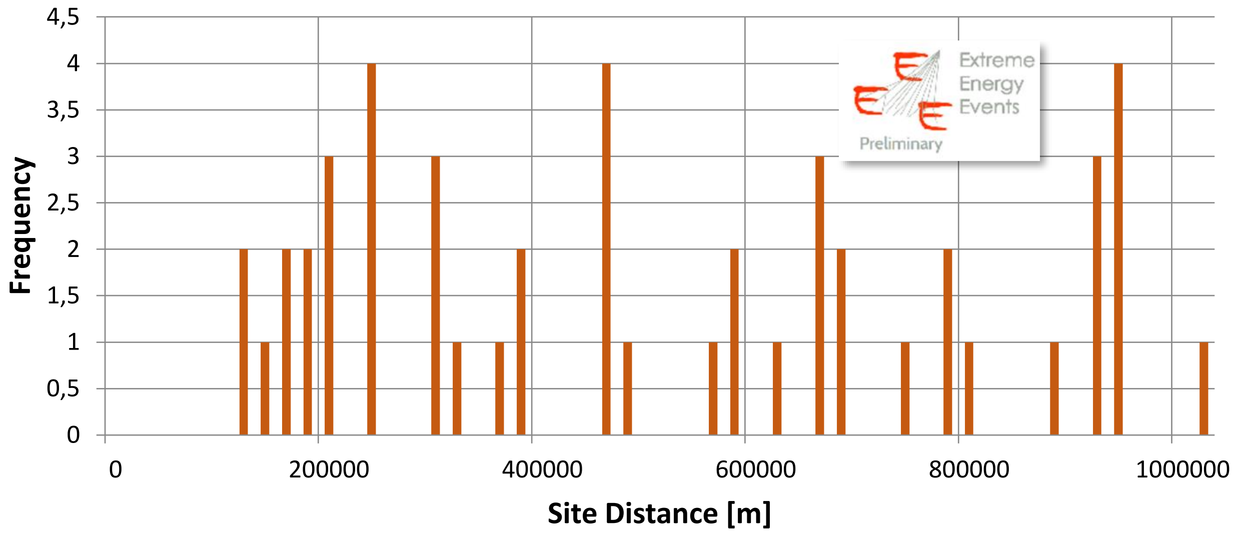


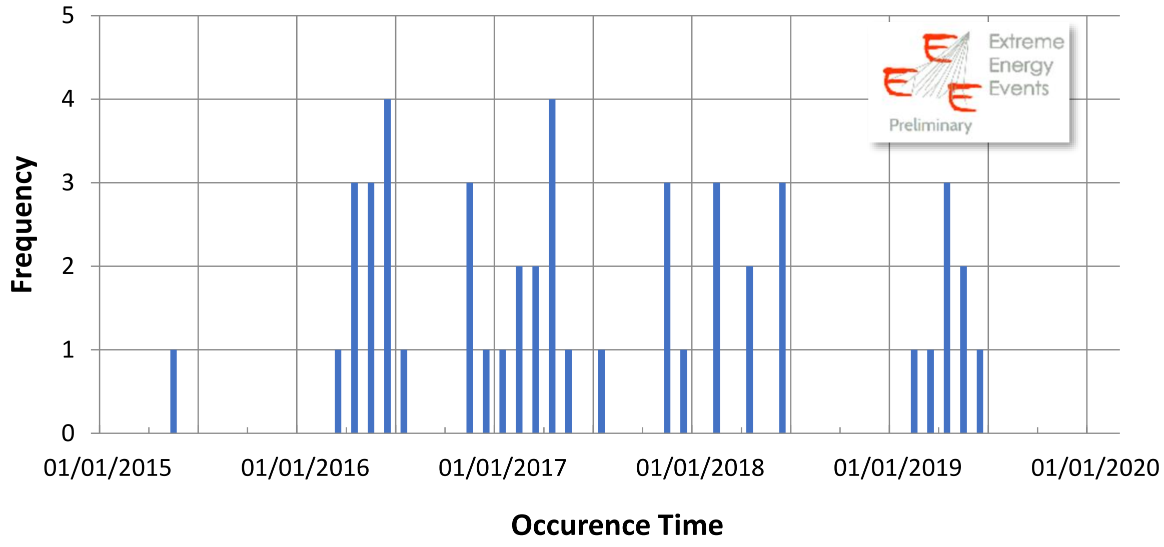
Events excess observed for:
$\Delta T \sim 10^{-5} \div 10^{-4}$ s
no. of tracks > 3

48 coincident events observed
29 events of expected background
Signal = 19 $\pm$ 9
S/B = 0.77 **$S/\sqrt{B}$ = 3.5** **p-value ~ 10^{-3}**

Characteristics of the candidate events

Time occurrence and site distance distributions for candidate events look almost uniform

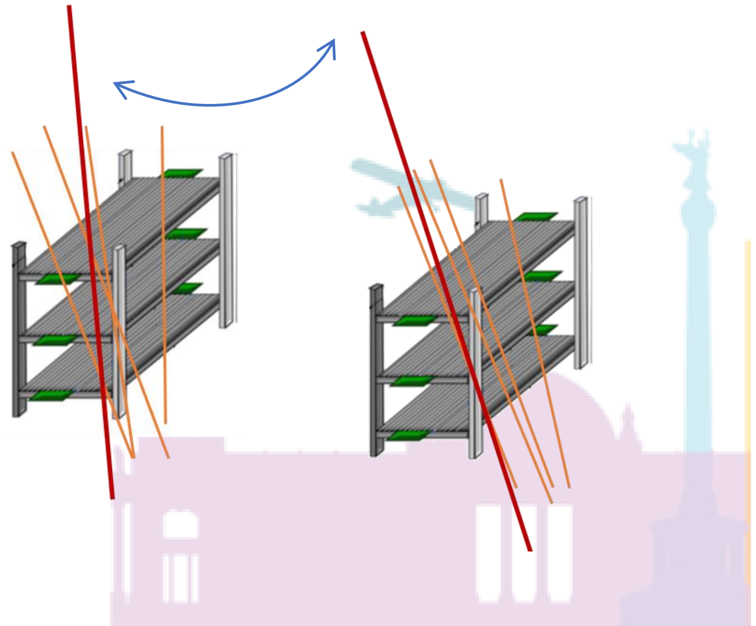




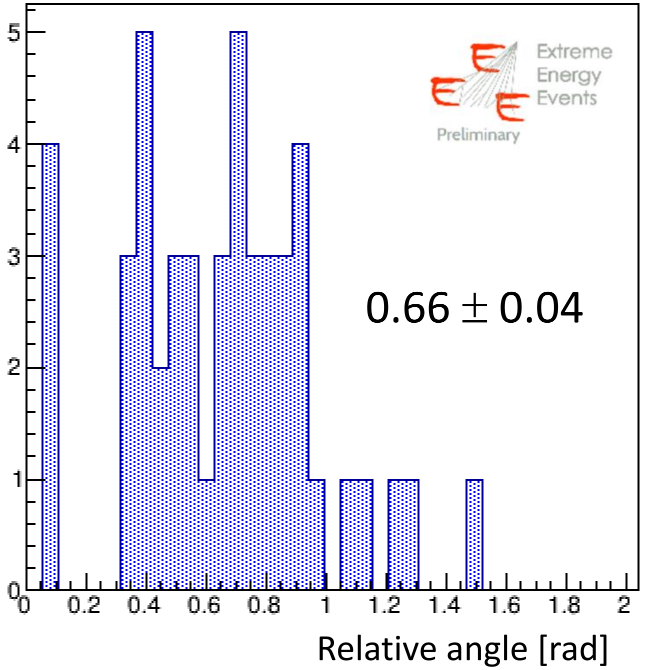
Characteristics of the candidate events

- Average direction extracted from tracks in each telescope
- Evaluated the relative angle between the average directions reconstructed in the 2 telescopes
- Check for parallelism (relative angle ~ 0)

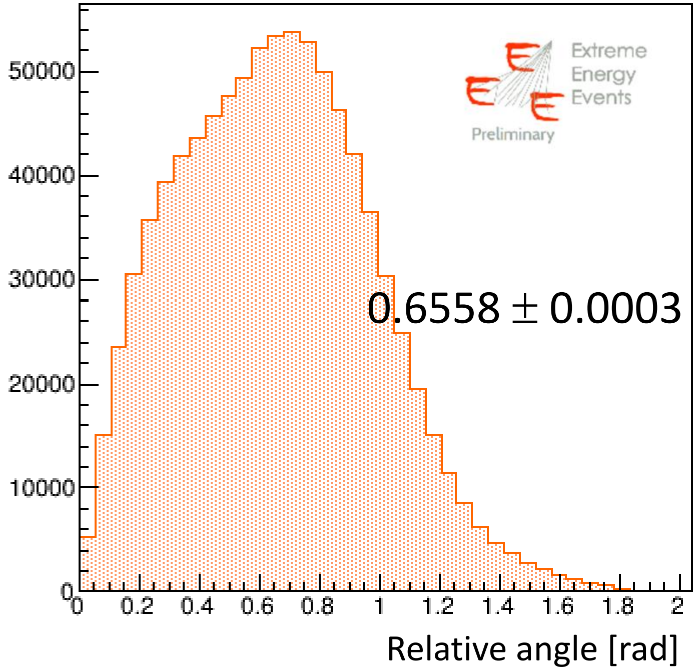
Candidate events seem to be correlated in time but not in orientation



Candidates



Background



Conclusions and outlook

- Network successfully operating for 17 years with excellent performance
- Most of the data collected analysed and many results already published

The number of telescopes, the network extension and the statistics allows to perform the search of long-range time correlations between EASs

- Different analysis approaches adopted (Eur. Phys. J. Plus 133 (2018) 34)
- **First hint of detection of time correlated EASs!**
- Next steps: optimization of the cuts, deep investigation of the characteristics of the candidate events

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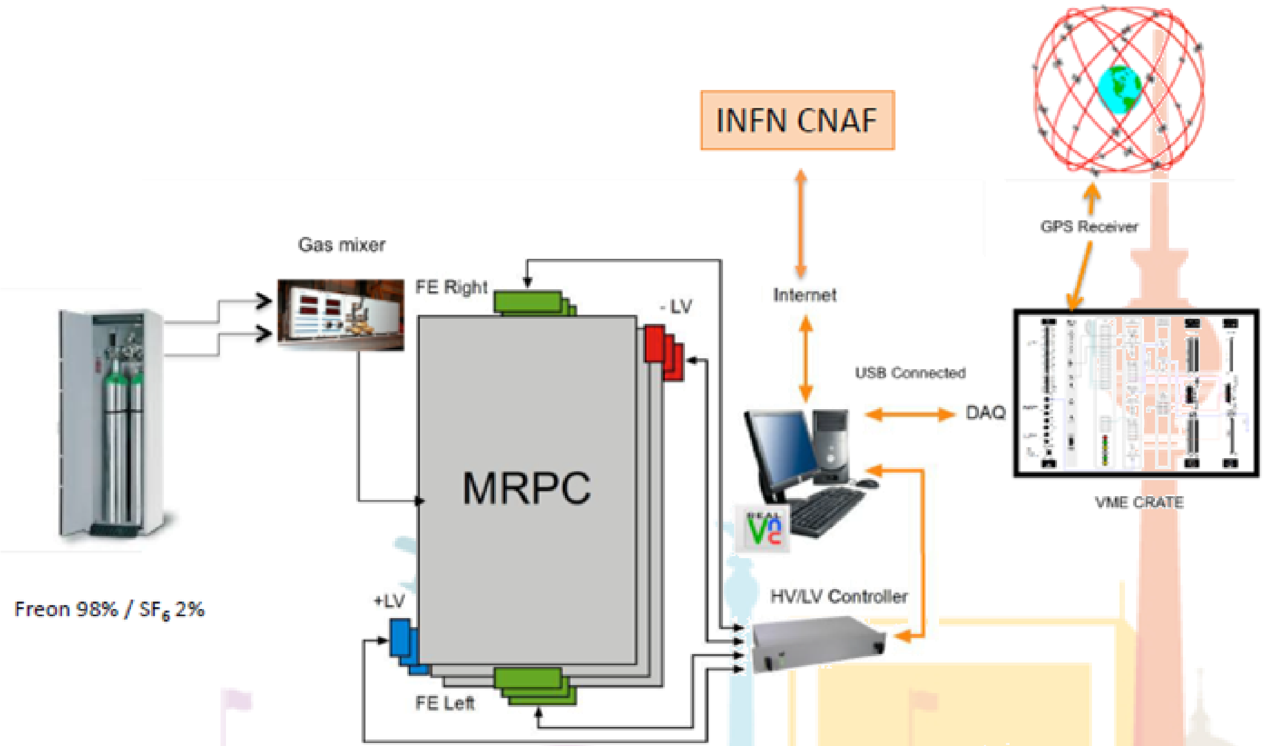
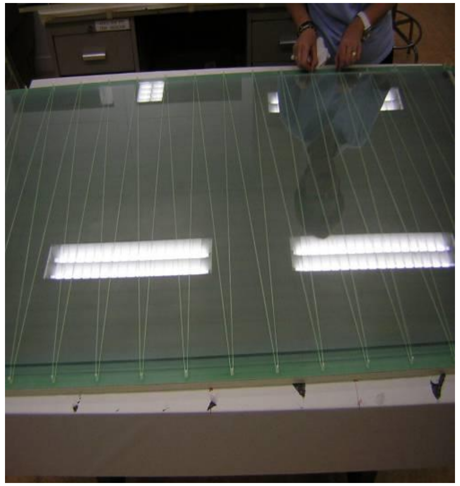
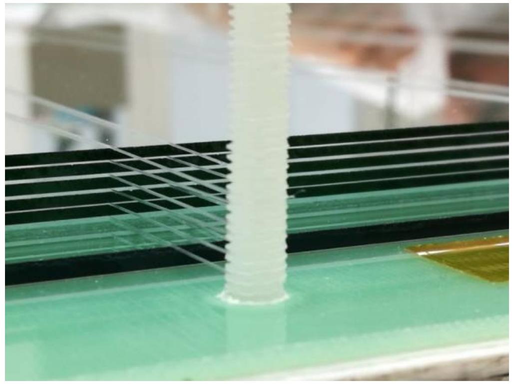
Backup

EEE telescopes

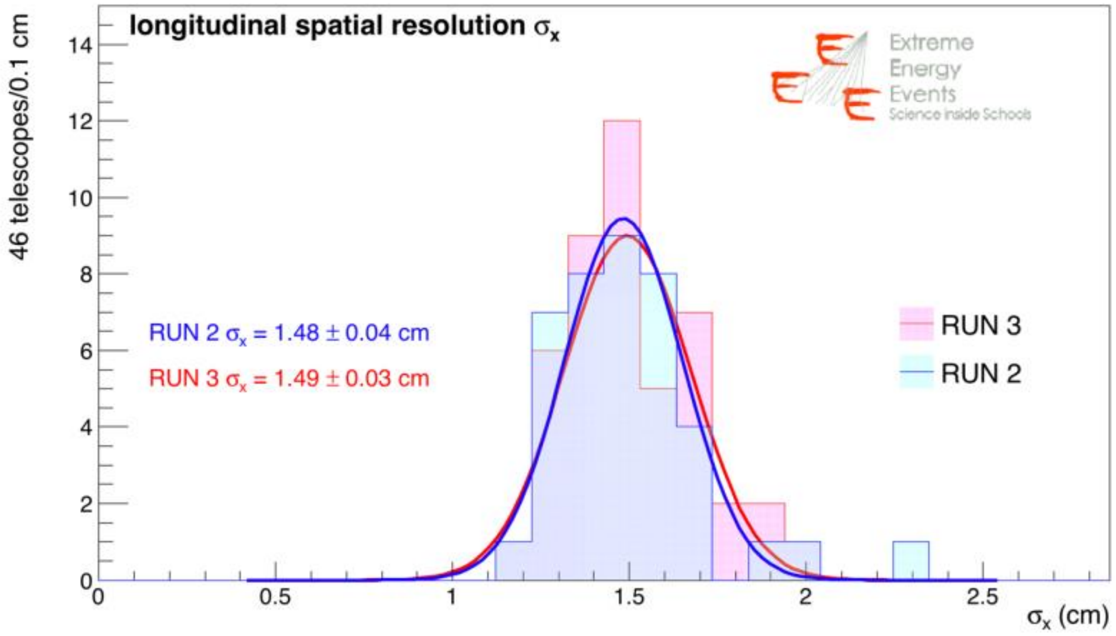


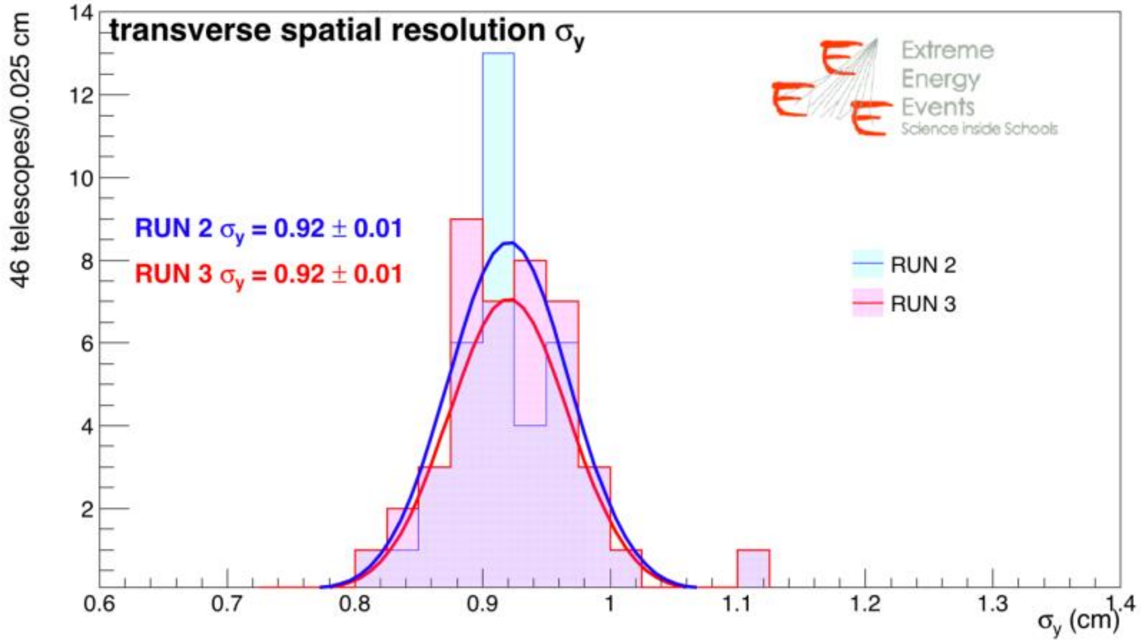




Spatial resolution of EEE chambers

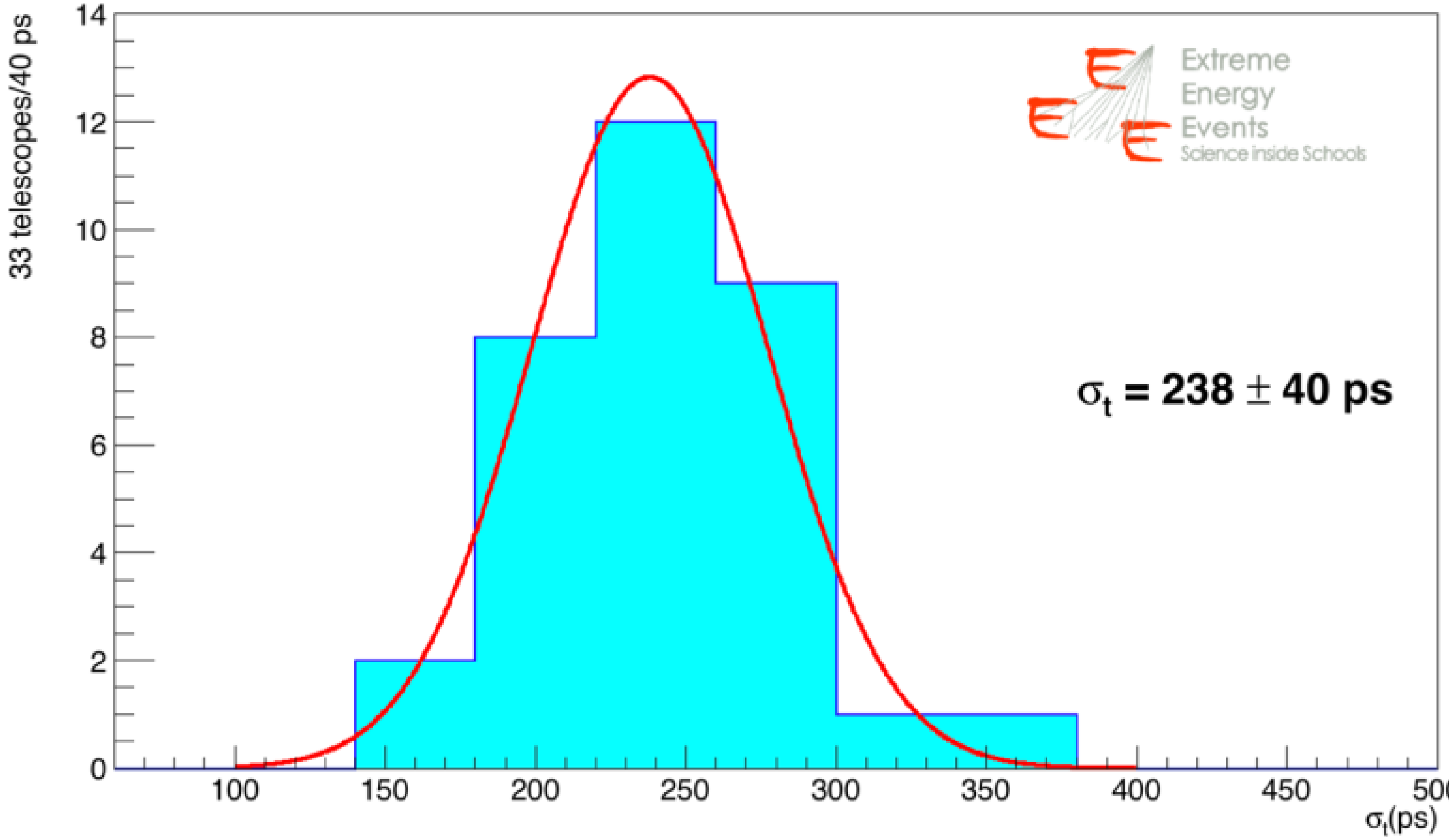
JINST 13(2018) P08026, arXiv:1805.04177v1





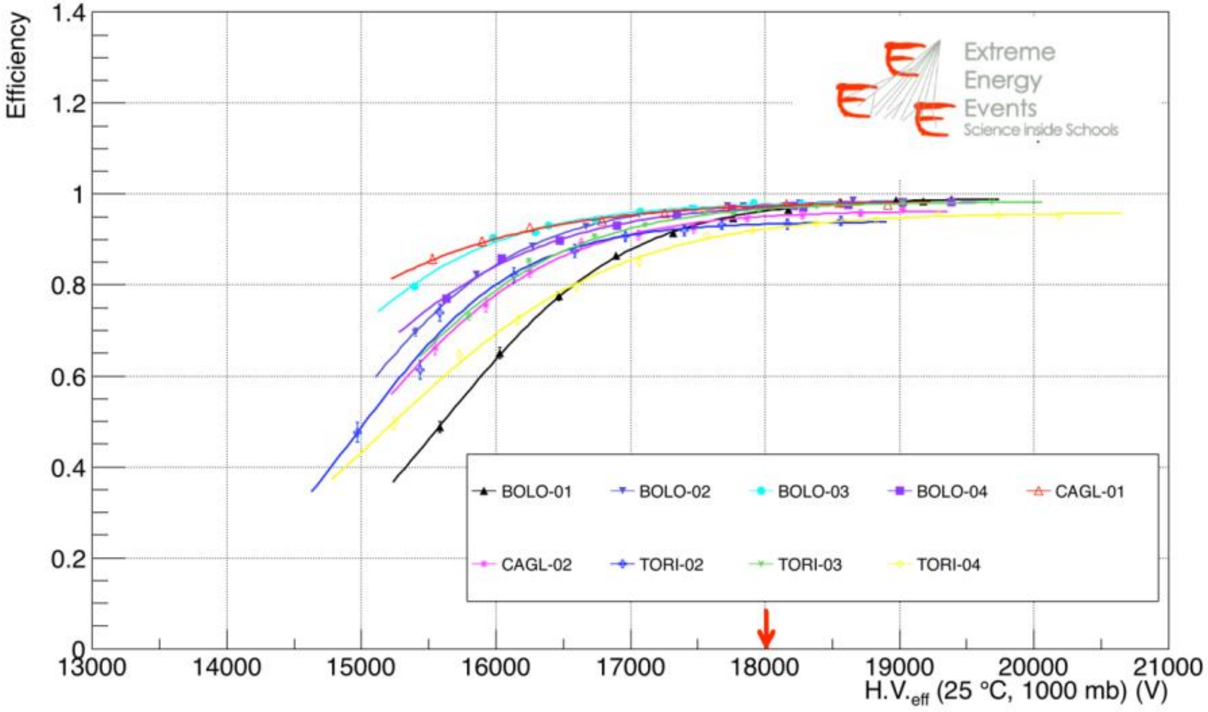
Time resolution of EEE chambers

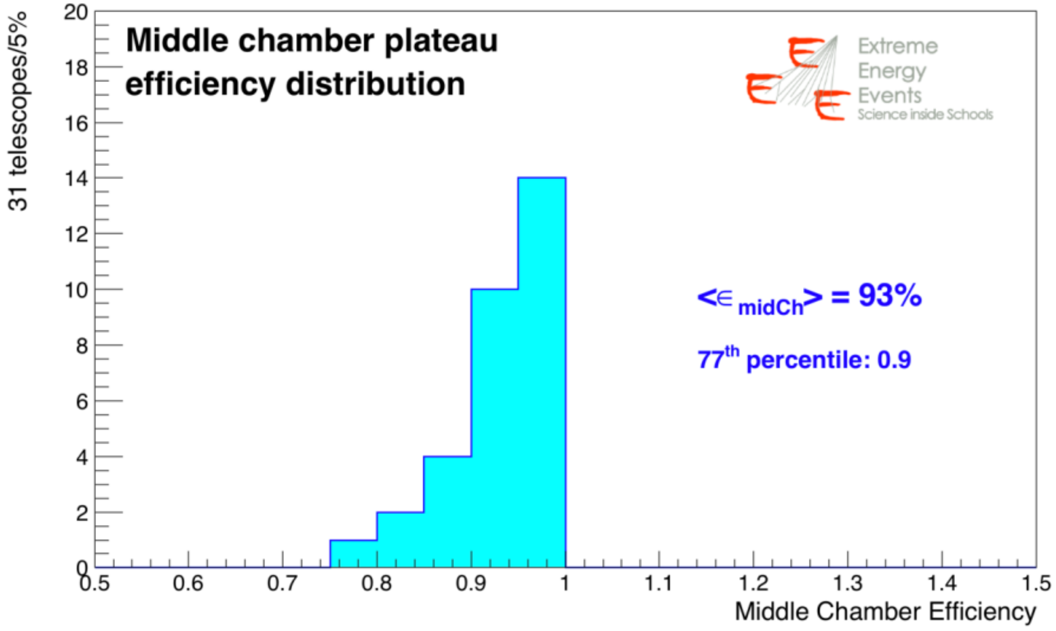
JINST 13(2018) P08026, arXiv:1805.04177v1



Efficiency of EEE chambers

JINST 13(2018) P08026, arXiv:1805.04177v1



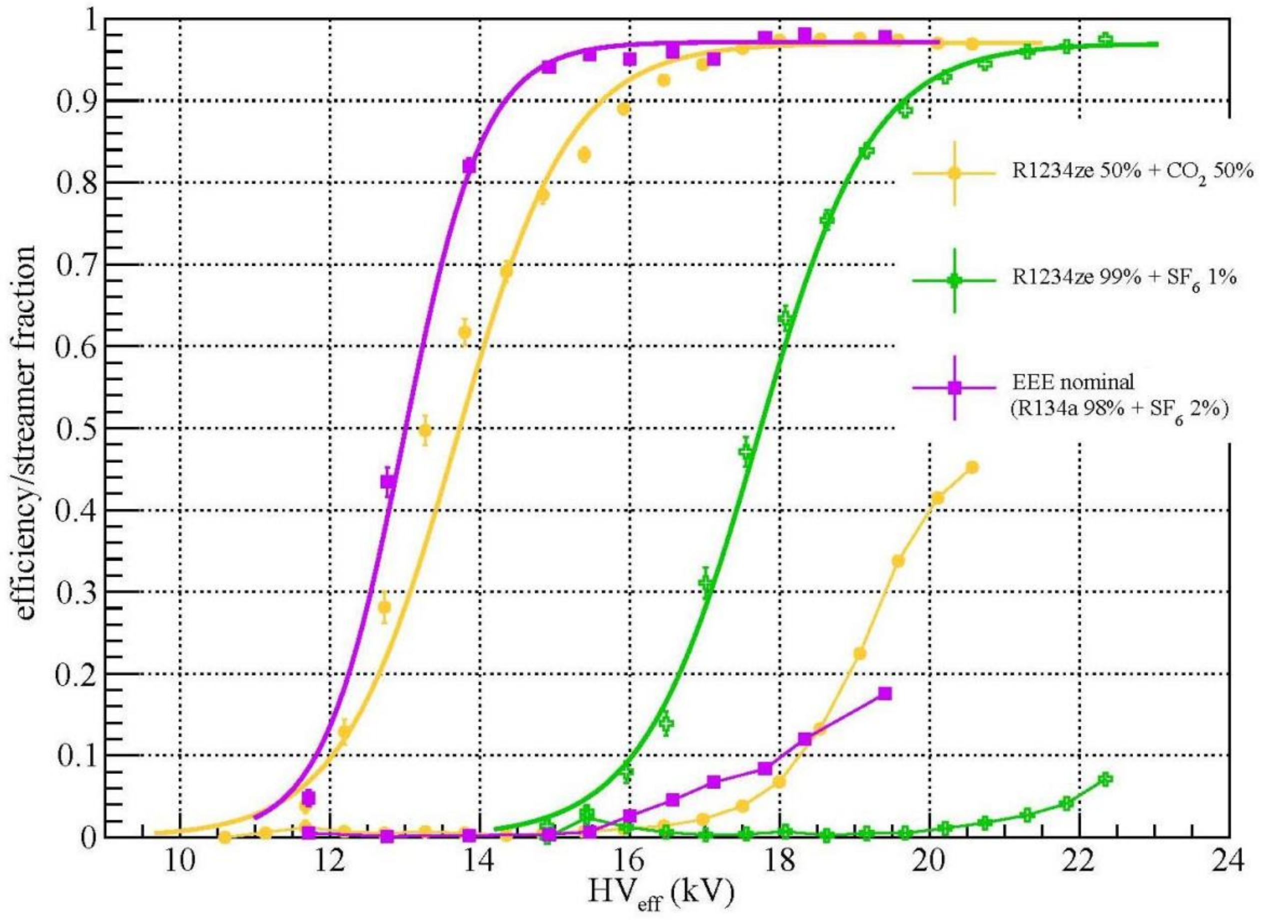


Test of eco-friendly gas mixtures

Most promising configurations:

R1234ze(50%) + CO_2 (50%)

R1234ze(99%) + SF_6(1%)



Outreach activities

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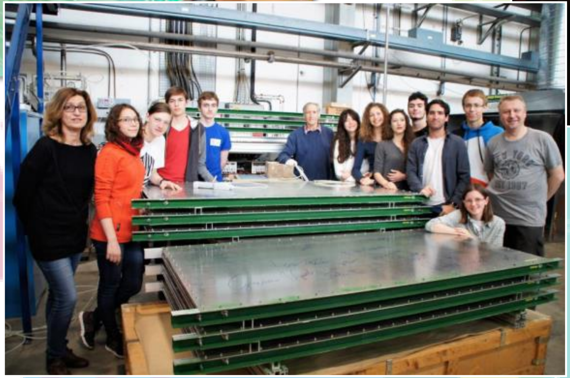
- The EEE telescopes are installed in Italian high schools
- High school students and teachers have built their own telescope at CERN and take care of the data taking
- Introducing high-school students and teachers to high energy physics
- Many activities organized or coordinated by Centro Fermi





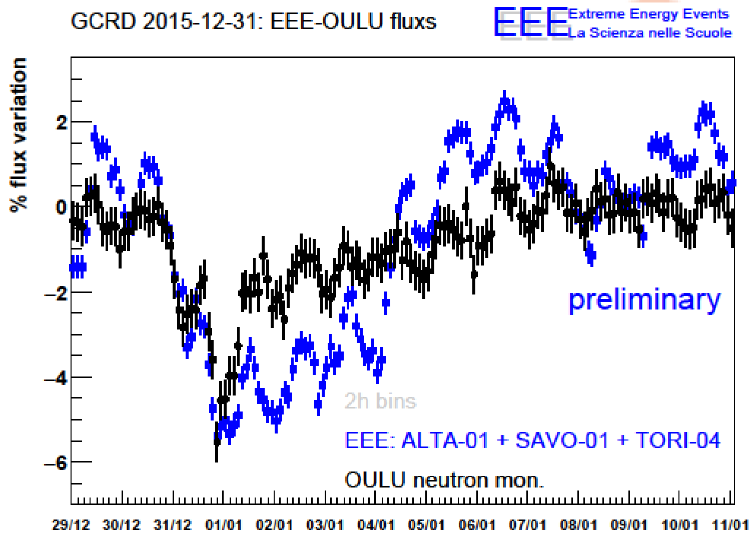



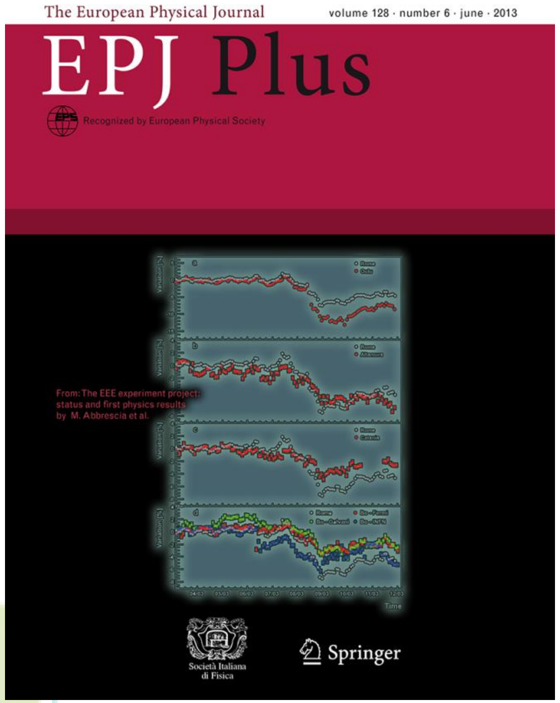
TALKS:
M. Abbrescia
C. Pinto

Physics results

Forbush decrease

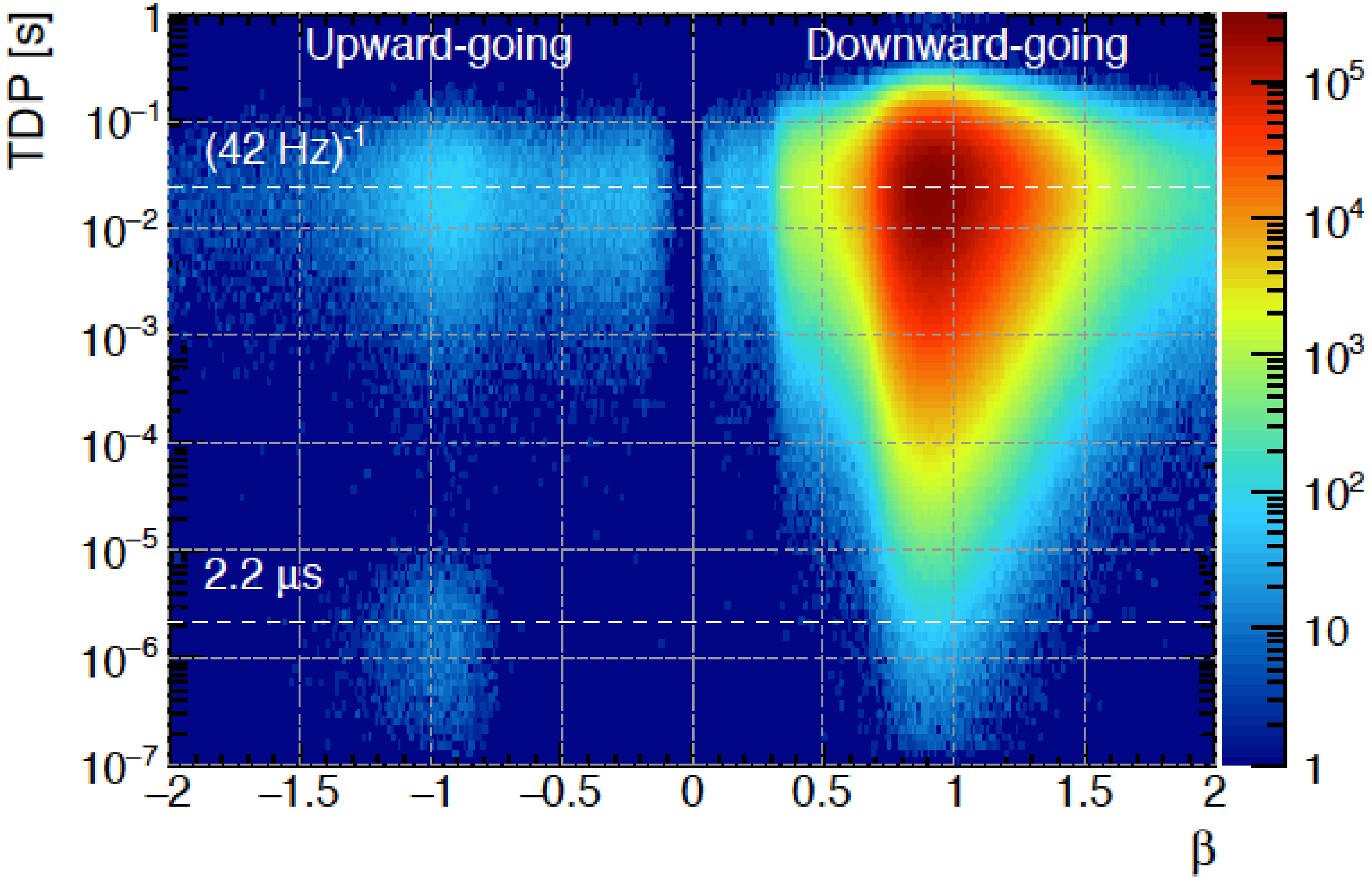
- Probably related to solar flares and the associated geomagnetic disturbances
- Characterized by a rapid (a few hours) intensity reduction, followed by a slow recovery in a few days time range
- Usually measured by neutron monitors





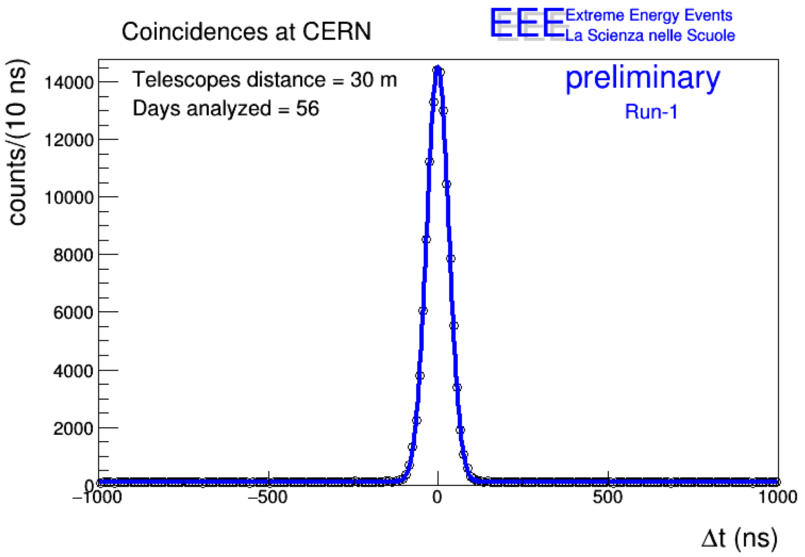
Physics results

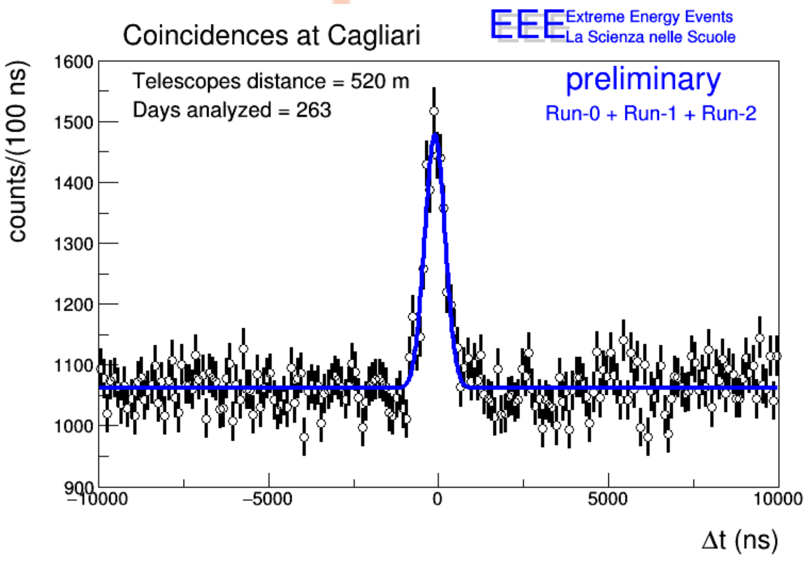
Upward going particles

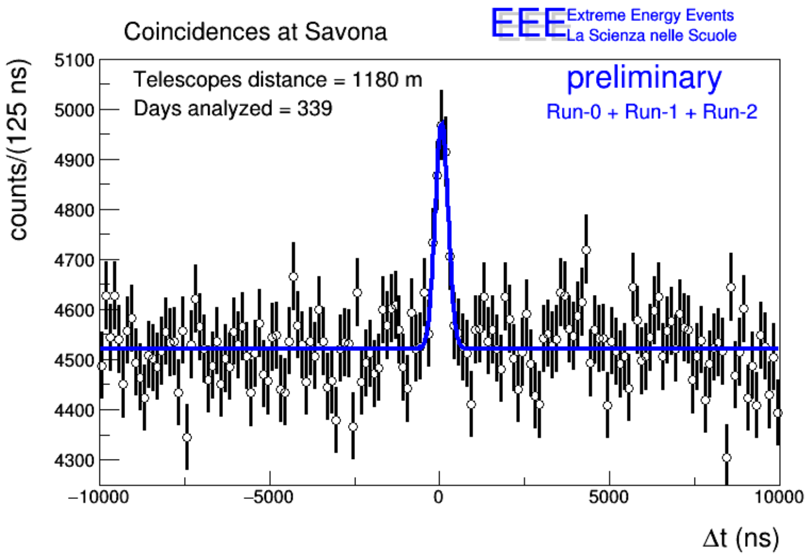


Physics results

EAS detection



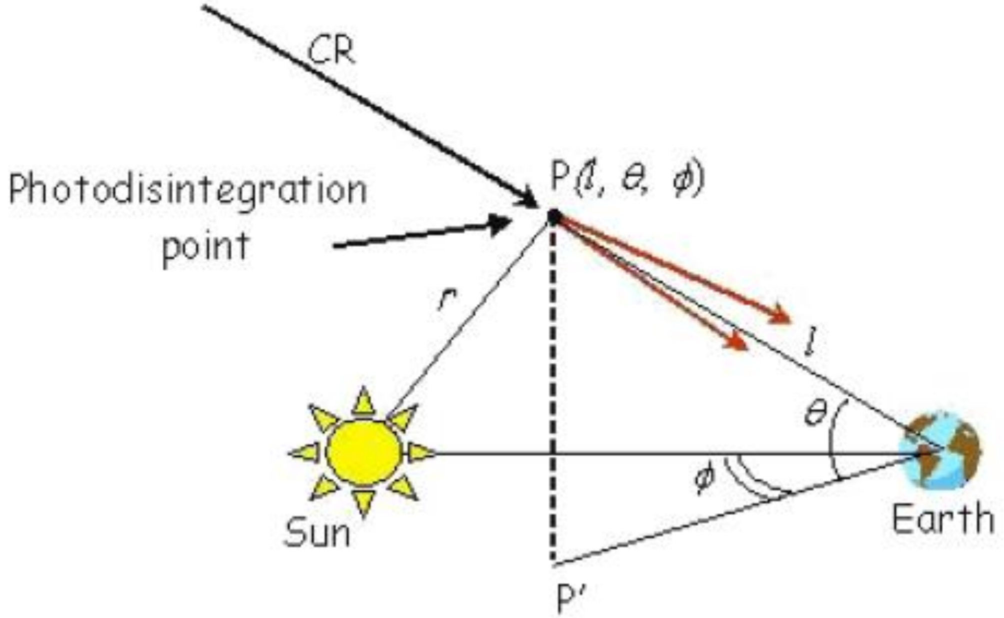




Gerasimova Zatsepin (GZ) effect

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

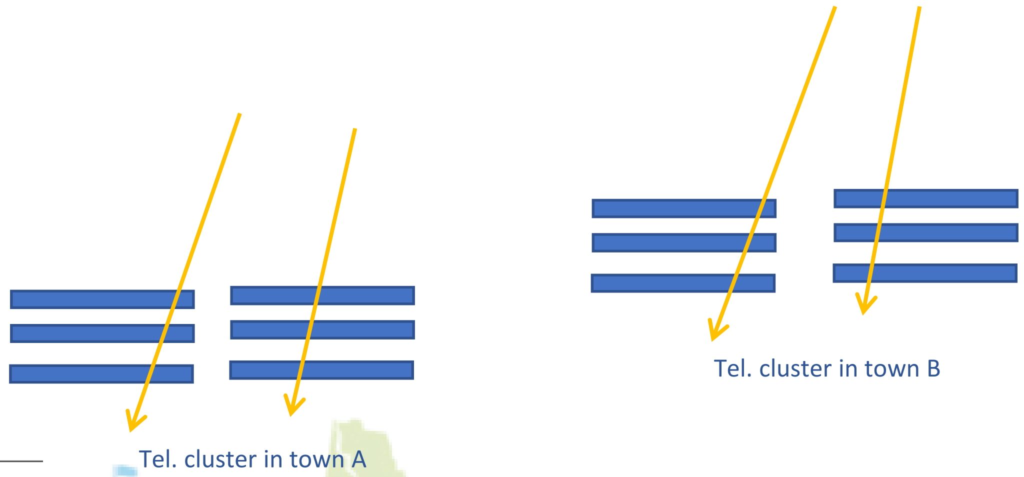
→ **Few GZ events expected per year**

Observation of few candidates reported by the LAAS collaboration

Correlations between telescope pairs

$R_{spurious}$ ~ 2 x 0.04 x 0.001 x 10^{-3} = 8 x 10^{-8} Hz (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)	ϑ_{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

Multi-track events (p-value)

p-value: how likely it is that data could have occurred under the null hypothesis

Minimum p-value was obtained for:

$\Delta T \sim 6 \times 10^{-5}$

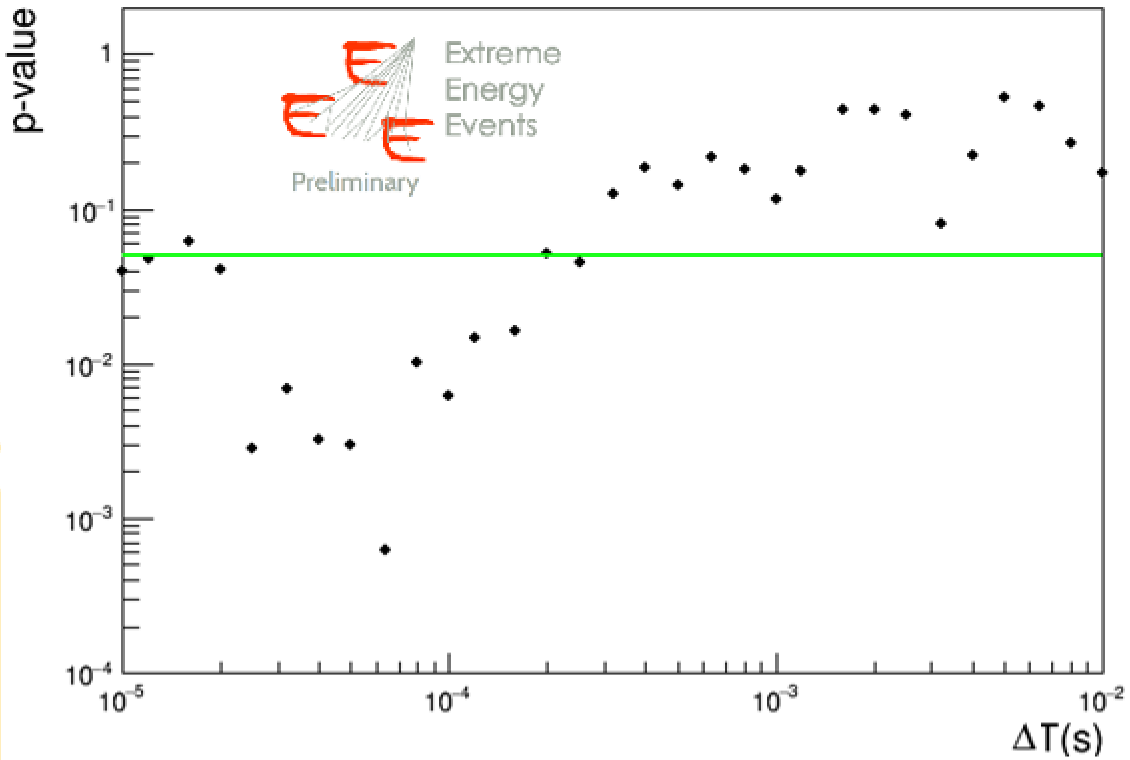
CUTS: n. tracks > 3, distance > 5 km

48 coincident events observed

29 events of expected background

Signal = 19 ± 9

S/B = 0.77 **S/√B = 3.5**



Combined analysis of multi-telescope events

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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)

Combined analysis of multi-telescope events

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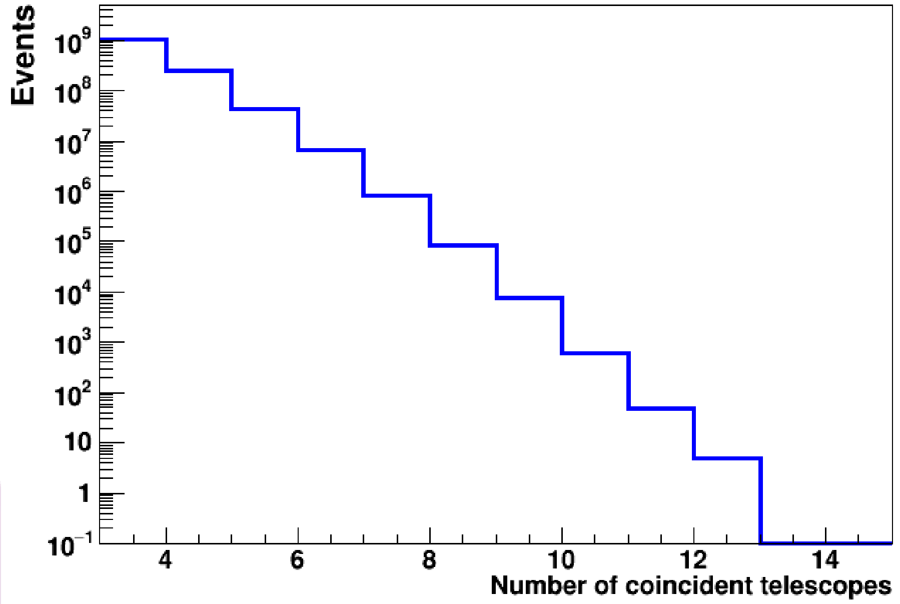
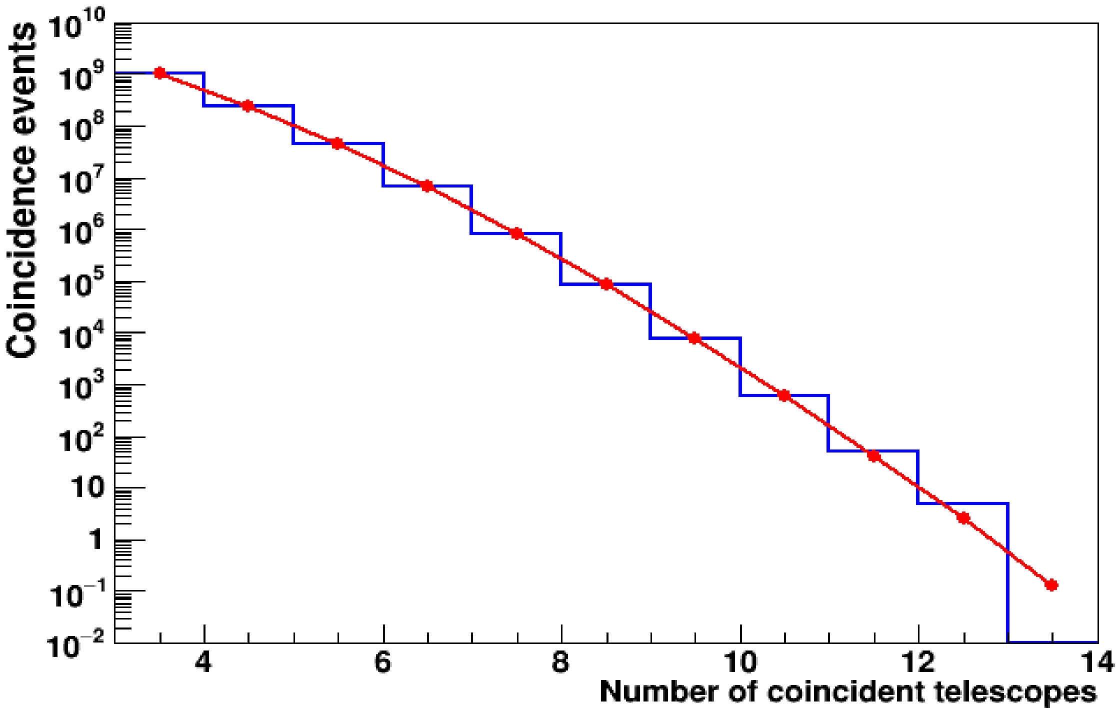
- A nearly complete scan of all available statistics from RUN 5 (October 2018-June 2019, 244 days) carried out
- Extraction of the raw multiplicity spectrum (number of coincident events as a function of the number of telescopes)



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

Combined analysis of multi-telescope events

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.