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

Extreme Energy Events

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EUROPEAN PHYSICAL SOCIETY HEP2019

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

The EEE Experiment

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

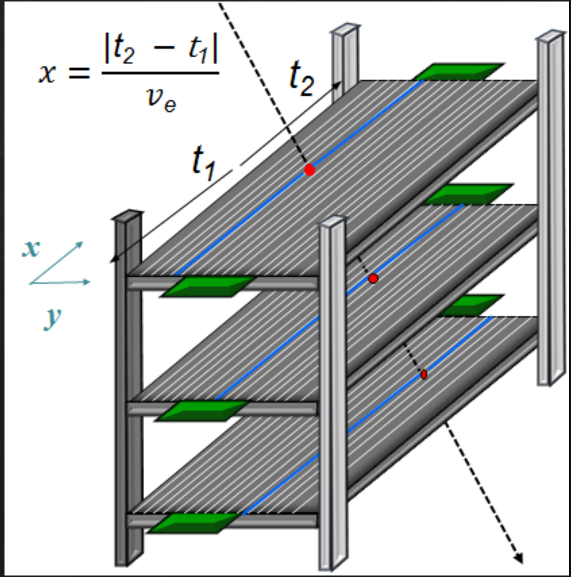
  Total: 62 telescopes
- + ≈ 50 institutes on the waiting list

http://eee.centrofermi.it

The MRPC telescope

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

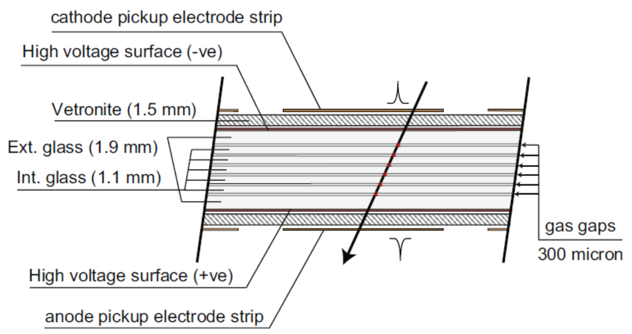
- Reasonable cost
- Long term operation required
- Efficiency close to 100 %
- Reconstruction of muon orientation
- Good time resolution (TOF measurements)

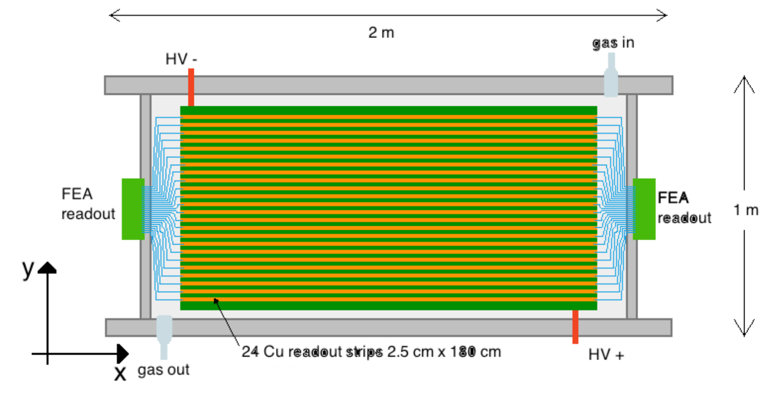


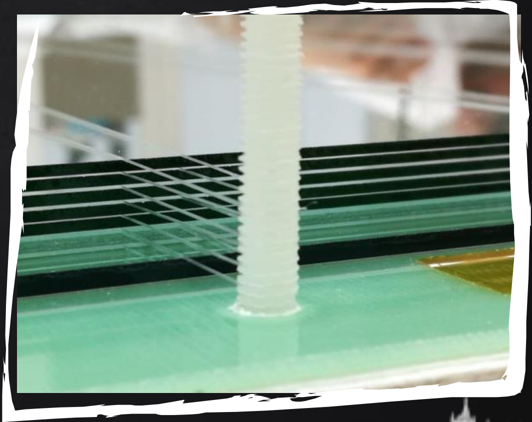
The MRPC of the EEE Project

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

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

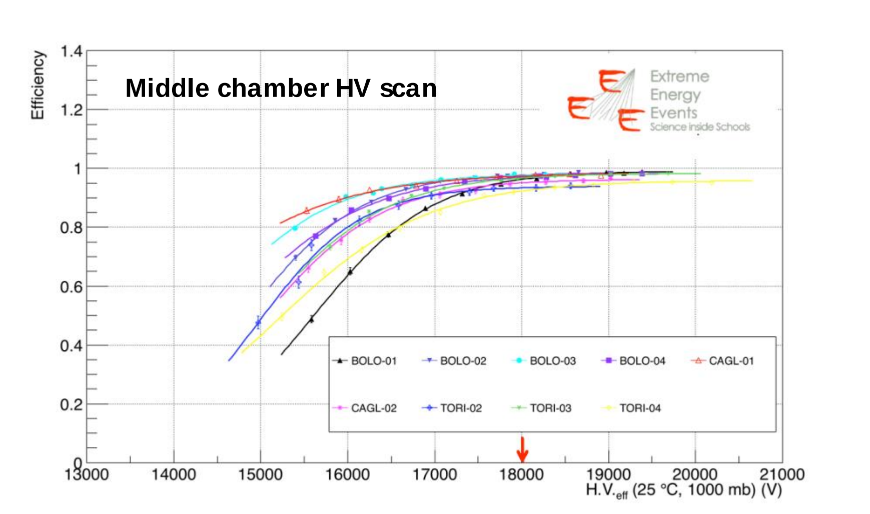


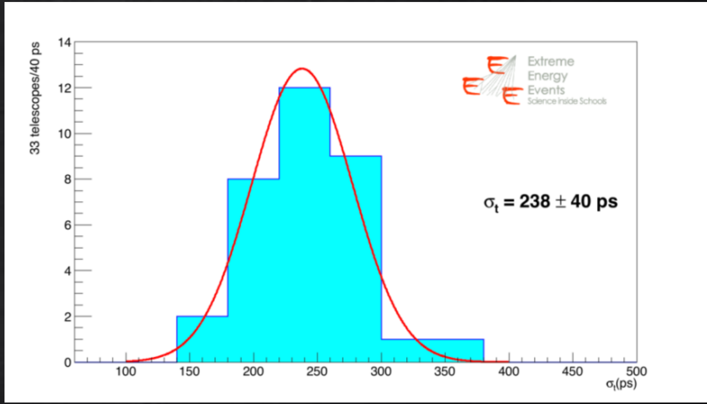




Performance of The EEE MRPCs

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



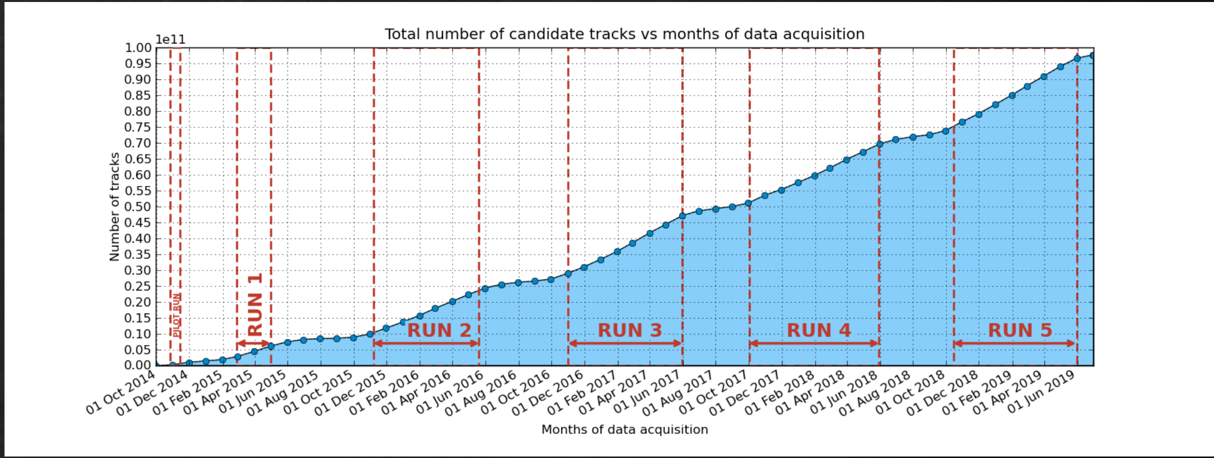


Very good performance compatible with EEE requirements

JINST 13(2018) P08026

DATA TAKING AND UPGRADE

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



Upgrade plans:

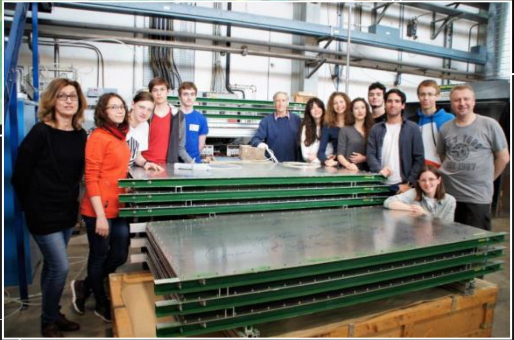
- Recently built new 50 chambers (new telescopes and spares)
- New test protocol at CERN
- New 250 µm six -gap chambers (lower operating voltage, eco-friendly gas)
- Improved FE boards
- New trigger & GPS board

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

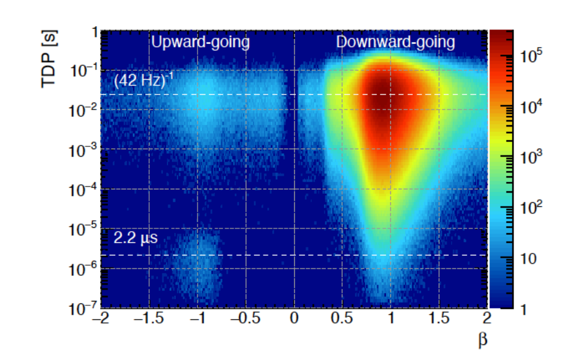
Physics goals

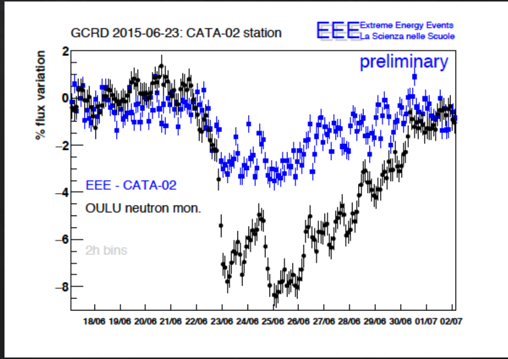
Examples of analyses carried out by the EEE Collaboration:

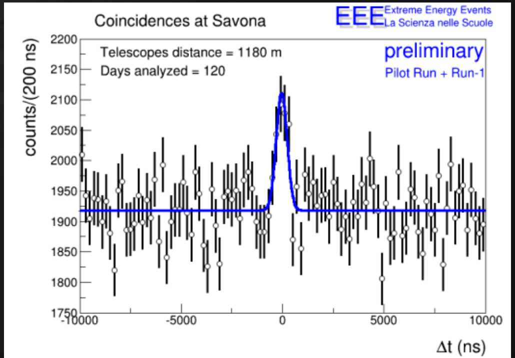
- Search for anisotropies of the secondary component
- Forbush decrease
- Upward going particles

single telescopes

- Detection of Extensive Air Showers — 2 or more telescopes in the same town
- Time Correlations between far telescopes — telescopes at distance > EAS extension







Time correlations between far telescopes

Extreme Energy Events

1. Long-distance time correlations between far telescopes

2. Coincidence events involving a large number telescopes

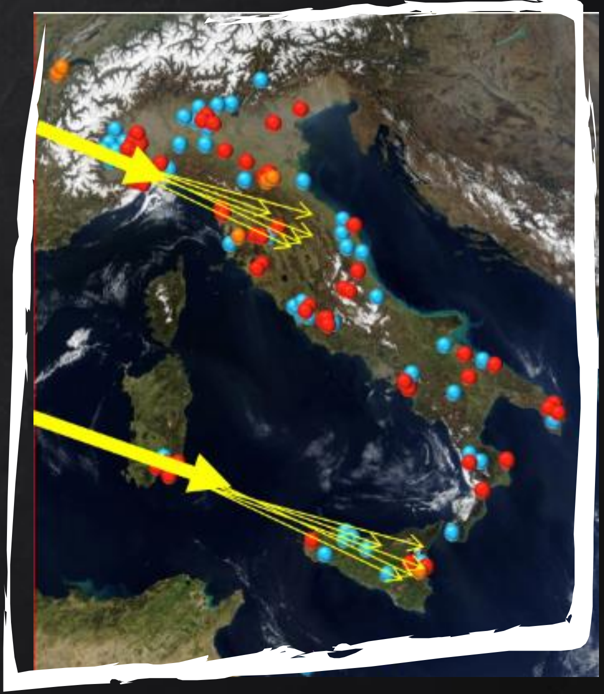
Time correlations between far telescopes

1.
Long-distance time correlations between far telescopes

2.
Coincidence events involving a large number telescopes

Long distance correlations between far telescopes (1.)

- 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

1.

RARE EVENTS ⟶ NEGLIGIBLE BACKGROUND NEEDED

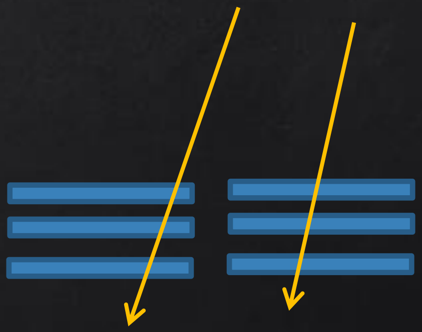
Several analysis strategies adopted:

Correlations between telescope pairs (extensive air showers)

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

Event	EEE pairs	Distance (km)	$\lvert t_1 - t_2 \rvert$ (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

- 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



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

LDC: Analysis strategies

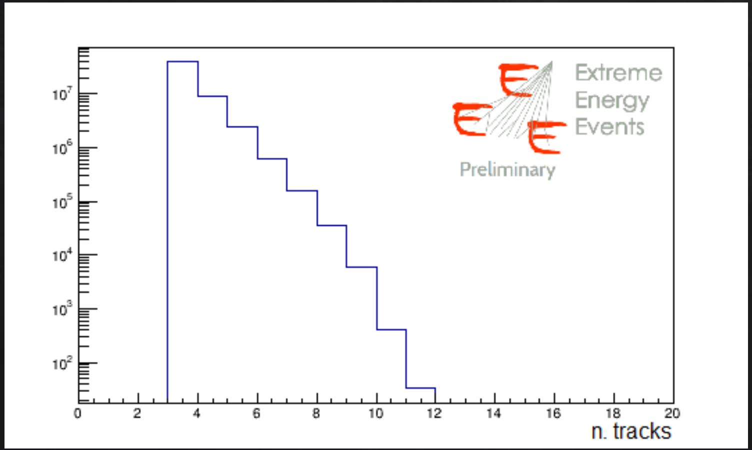
1.

RARE EVENTS → NEGLIGIBLE BACKGROUND NEEDED

Several analysis strategies adopted:

Correlations between multi-track events in both telescopes

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



LDC: Analysis strategies

1.

Pre - selection of multi-track events:

Chi2 < 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:

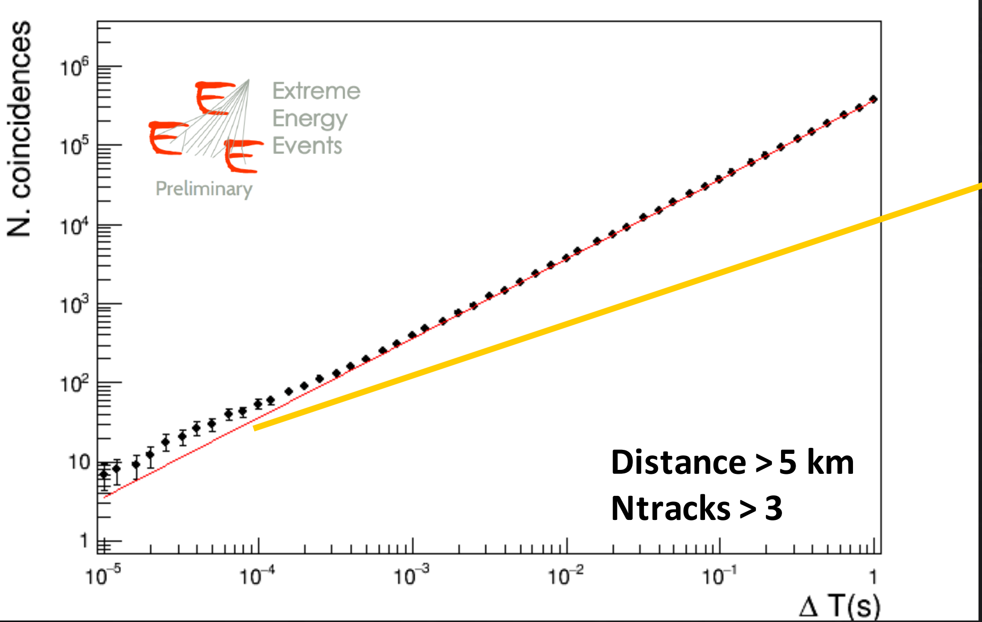
Telescope distance > 5 km

Ntracks > 3 on both telescopes

LDC: PRELIMINARY RESULTS

1.

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 ~ 23.4 events) p-value ~ 10^{-3}

Cuts optimization ongoing:

- Multi-tracks events selection (parallelism and quality)
- N. of tracks
- Site distance
- Relative angle

Time correlations between far telescopes

Extreme Energy Events

1. Long-distance time correlations between far telescopes

2. Coincidence events involving a large number telescopes

COMBINED ANALYSIS OF MULTI-TELESCOPE EVENTS

2.

Extreme Energy Events

Combined analysis of multi-telescope events

2.

Extreme Energy 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

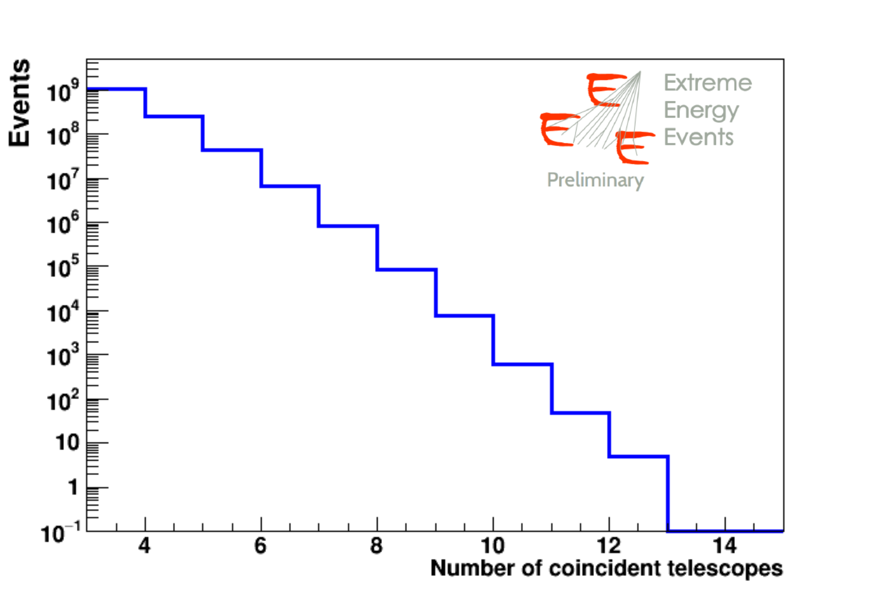
2.

- 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

2.

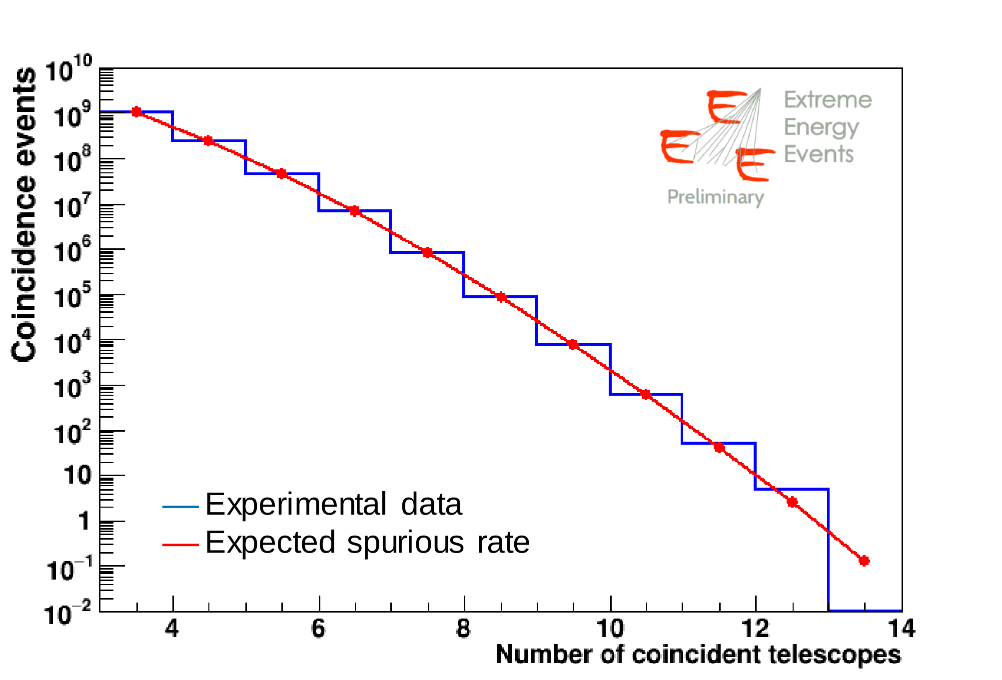
- Highest multiplicity events observed: 5 events with 12 telescopes
- Roughly a factor 10 decrease in the yield for every additional telescope



Preliminary results

2.

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 cosmics phenomena
- High school students strongly involved in the Project

Time correlations between far telescopes

- Different analysis approaches adopted
- Preliminary results extracted
- Next steps:

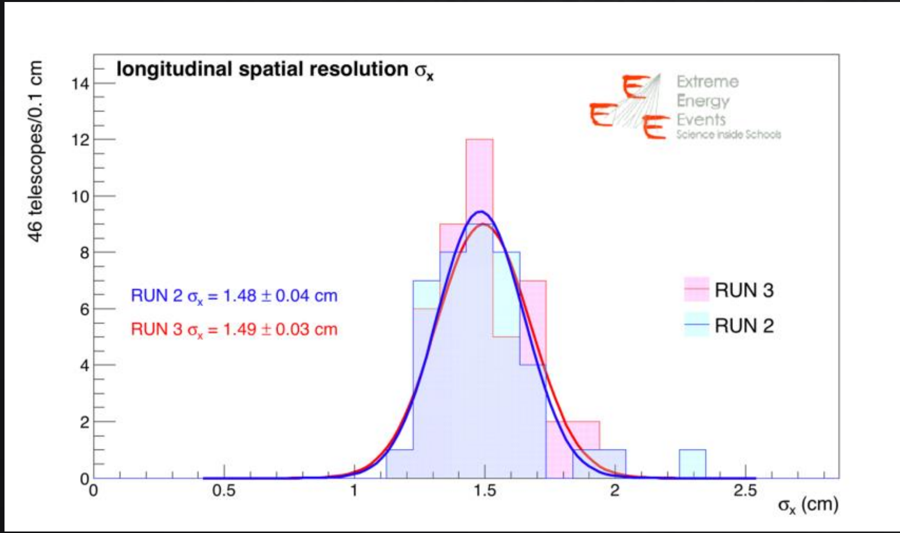
1.
  - optimize the cuts
  - investigate the excess of events
  - increase the statistics

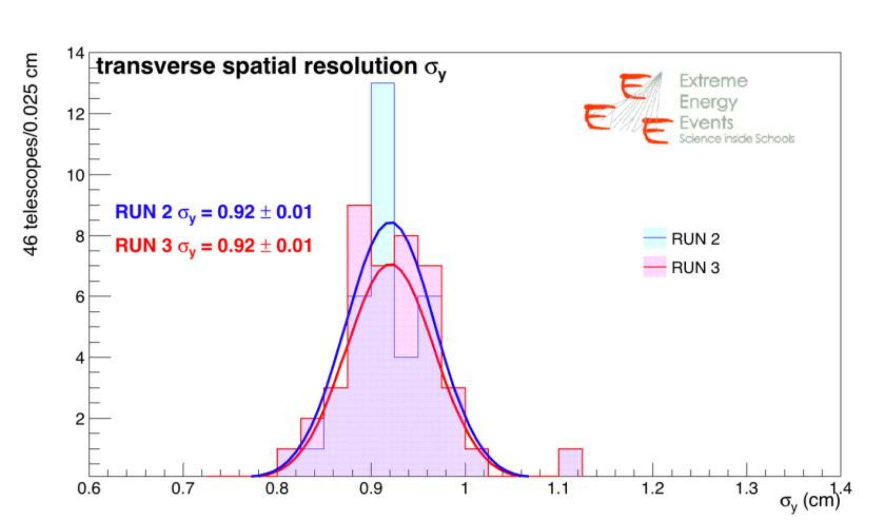
2.
  - check the effect of various assumptions on the spurious rate (average number of telescopes, individual rates, efficiency,…)
  - repeat the analysis for multi-tracks
  - increase the statistics

The very last slide

THANK YOU FOR THE ATTENTION!

SPATIAL RESOLUTION

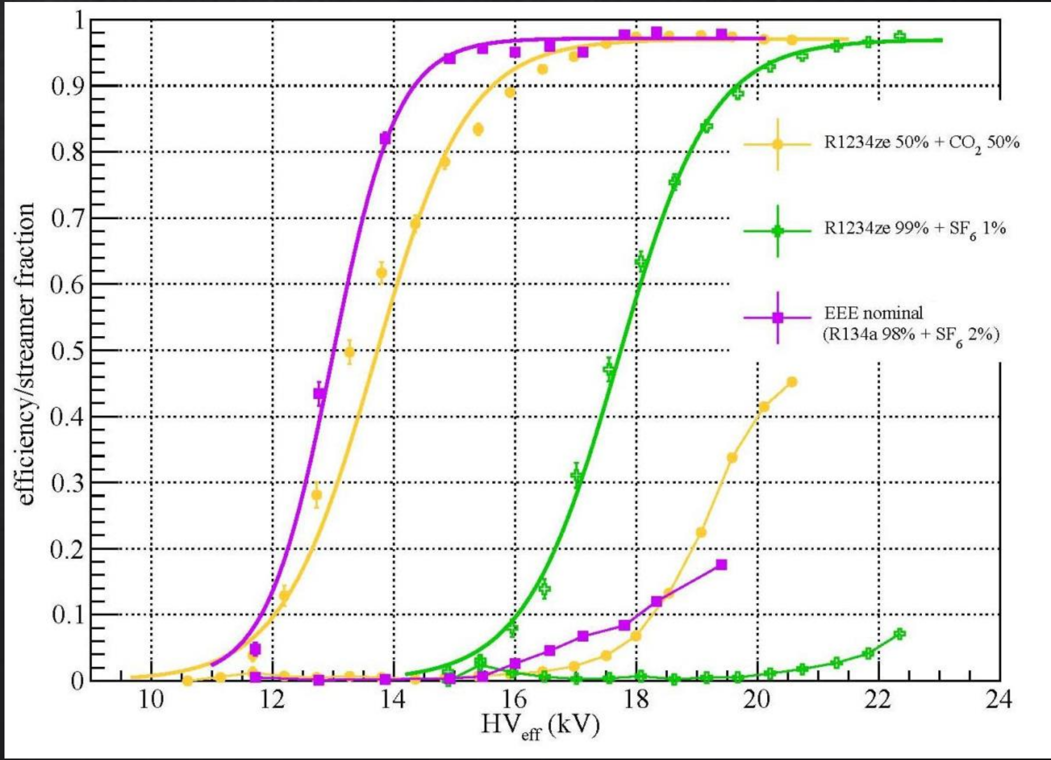




Test of eco-friendly gas mixture

Most promising configurations:

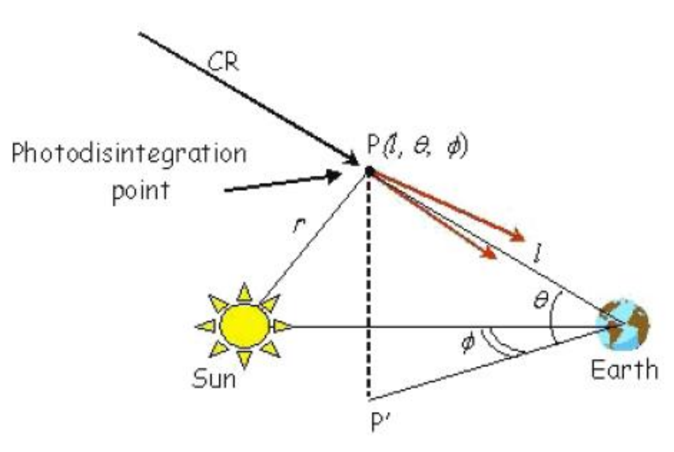
R1234ze(50%) + CO_2 (50%)
R1234ze(99%) + SF_6(1%)



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

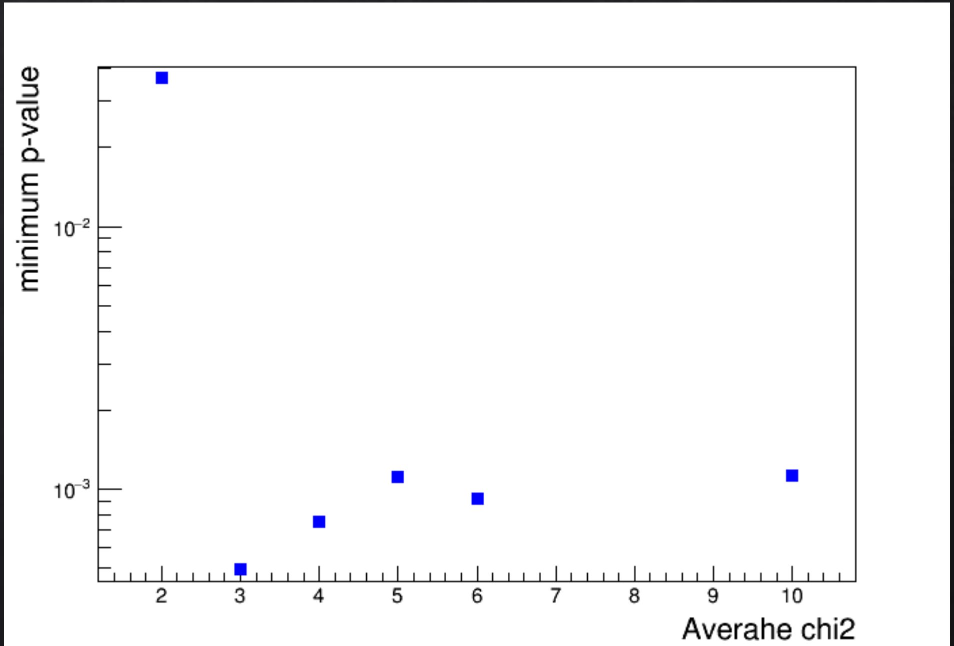
→ Few GZ events expected per year

Observation of few candidates reported by the LAAS collaboration

Search for LDC with multi-track events

Several additional cuts investigated :

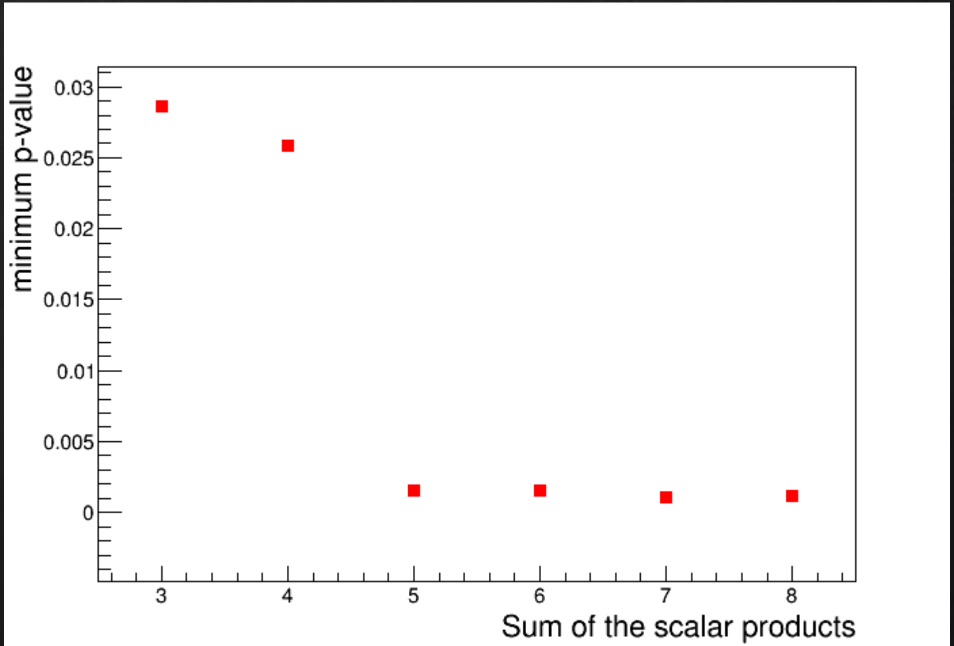
Effect of χ2



Search for LDC with multi-track events

Several additional cuts investigated :

Parallelism of the tracks

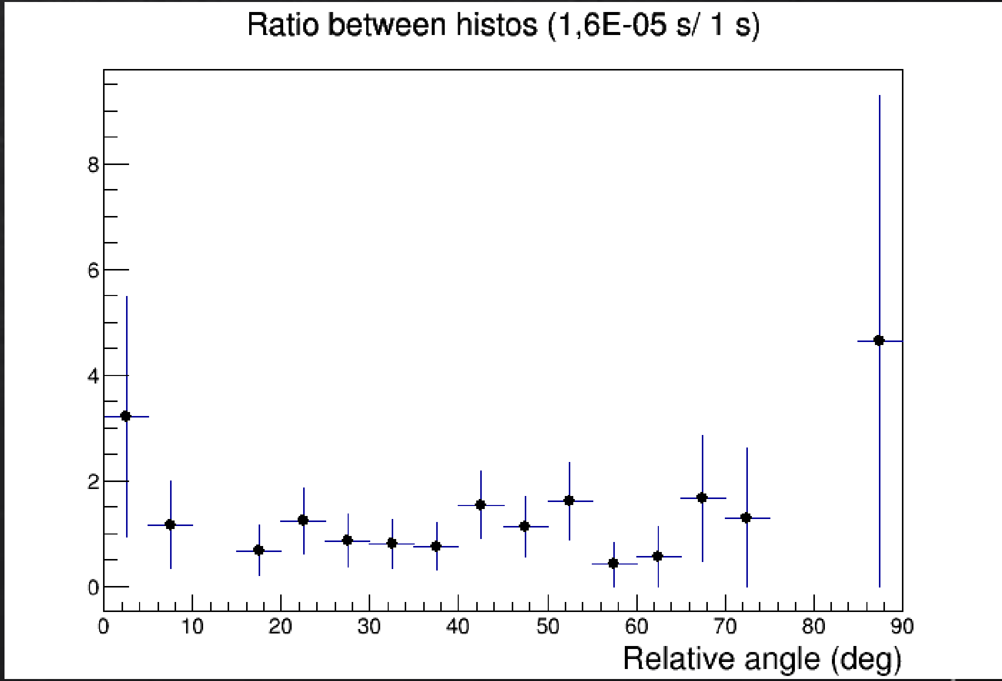


Search for LDC with multi-track events

Several additional cuts investigated :

Relative angle between EAS axis

Ratio w.r.t. random coincidences:
No significant differences seen with the relative angle



Backup

Expected average spurious rate for a specific combination of k telescopes

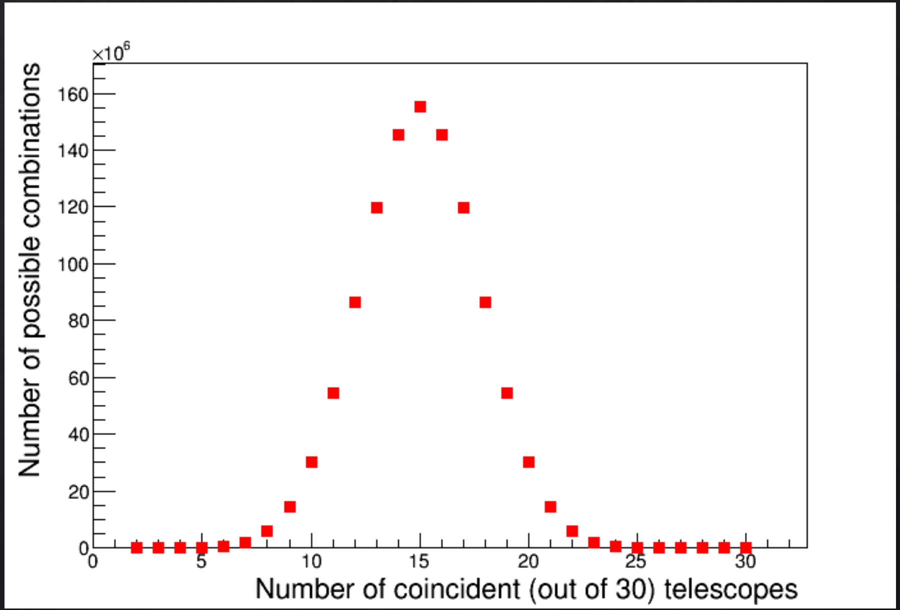
$$R\_spurious \sim N\,(R\_single)^{k} \times \Delta t^{\,k-1}$$

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

$$P_{n,k} = \binom{n}{k} = \frac{n!}{k!(n-k)!} = \frac{1}{k!}\prod_{i=0}^{k-1}(n-i)$$

Backup

Number of possible combination of telescopes out of 30 working

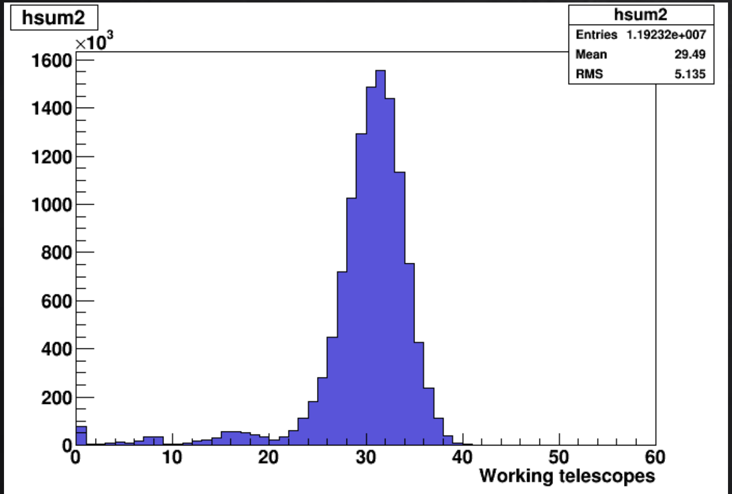


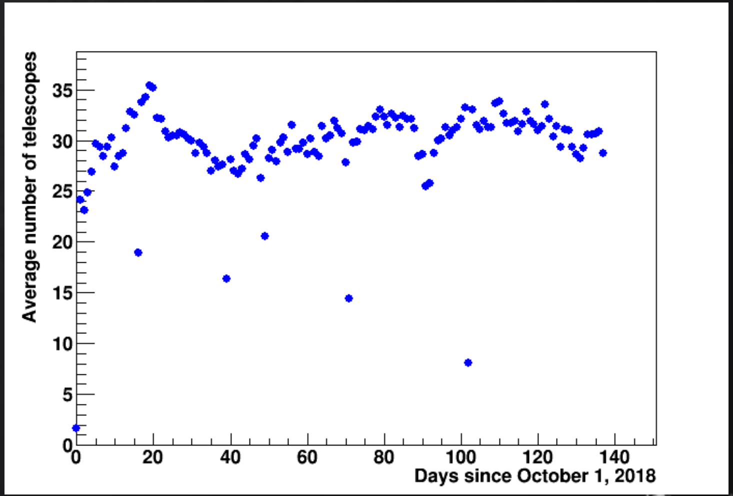
PRELIMINARY RESULTS

Comparison to the expected spurious rate

Assumptions:

- Individual incoming muon rate
- Detection efficiency
- Number of working telescopes/day





Backup

Assumed: 30 working telescopes
Average single rate from all telescopes: 29 Hz
Efficiency to be take into account