Small Extensive Air Shower detector array – measurements and estimation

Jerzy Pryga[1]

Under supervision of
Krzysztof Woźniak[2] and **Łukasz Bibrzycki**[3]

[1]University of the National Education Commission in Cracow,
[2]Institute of Nuclear Physics PAS,
[3]AGH University of Krakow

PAiP 21.02.25

Basic CREDO equipment

CREDO THE QUEST FOR THE UNEXPECTED

CREDO (**C**osmic-**R**ay **E**xtremely **D**istributed **O**bservatory) - collaboration searching for global cosmic ray related phenomena i.e. Cosmic-Ray Ensembles (CRE) [Homola et al., 2020].

Current main source of data: smartphones

Perfect Extensive Air Shower (EAS) detector for CREDO:

1. Very good temporal resolution ($< \mu s$).
2. Measures atmospheric CR flux with good statistics.
3. Distinguishes EAS from single particles.
4. Collects data remotely.
5. Works continuously for years.
6. Inexpensive and easy to manufacture in large number.

Basic CREDO equipment

THE QUEST FOR THE UNEXPECTED

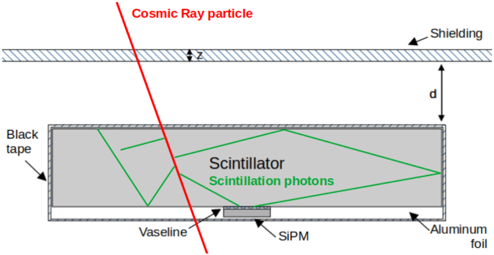
CREDO (**C**osmic-**R**ay **E**xtremely **D**istributed **O**bservatory) - collaboration searching for global cosmic ray related phenomena i.e. Cosmic-Ray Ensembles (CRE) [Homola et al., 2020].

Current main source of data: smartphones

Realistic EAS detector for CREDO:

1. OK temporal resolution ($\approx 100\ \mu s$ should be possible).
2. Measures atmospheric CR flux with good statistics.
3. Distinguishes EAS from single particles.
4. Collects data remotely.
5. Works continuously for years.
6. Inexpensive (1000-2000 EUR) and easy to manufacture in large number.

Constructed prototype



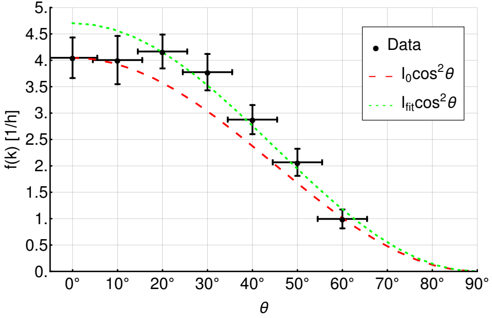
Small array of $5 \times 5 \times 1$ cm scintillator detectors [Axani, Frankiewicz, and Conrad, 2018]:

- 8 devices in a flat coincidence system.
- 200 ns coincidence time window.
- Data collected on SD card.

Measurement - angular distribution

Measurement 1:

Relationship between muon flux I_0 [1/h] and zenith angle θ (two detectors in a top-bottom coincidence setup).



Estimation of expected measurement results

CORSIKA simulations

↓

Particle density in EAS:
$\rho_{part}(E, \theta, \phi, r, N, h)$

+

Geant4 simulations

↓

Detectors efficiency:
$\eta_{part}(p)$

↓

Probability of k signals in coincidence in array of n detectors:
$Q(n, k)$

+

Literature

↓

Spectrum of primary CR:
$j(E) = j_0 E^{-\gamma}$

↓

Frequency of k-fold events: $f(k)$ [1/h]

Estimation of expected measurement results

CORSIKA simulations

↓

Particle density in EAS:
$\rho_{part}(E, \theta, \phi, r, N, h)$

+

Geant4 simulations

↓

Detector efficiency:
$\eta_{part}(p)$
+
Results from first measurement – $I(\theta)$

↓

Probability of k signals in coincidence in array of n detectors:
$Q(n, k)$

+

Literature

↓

Spectrum of primary CR:
$j(E) = j_0 E^{-\gamma}$

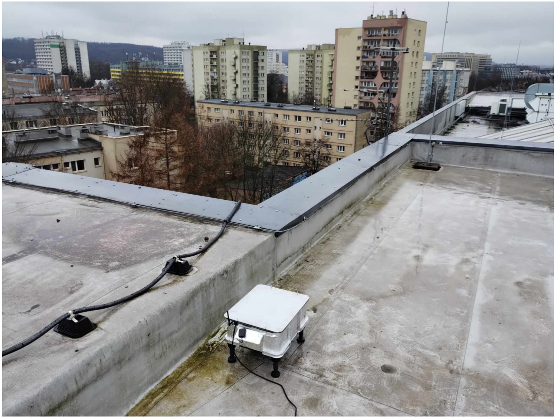
↓

Frequency of k-fold events: $f(k)$ [1/h]

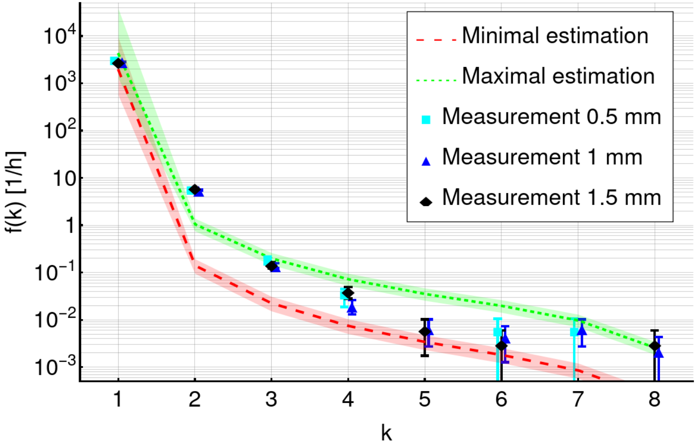
Measurement – detection of EAS

Measurement 2:

Array in a flat coincidence setup with various shieldings.



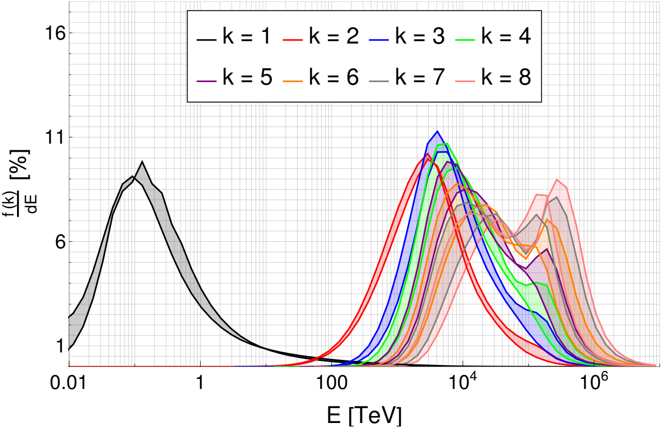
Measurement and estimation from simulations



– Measurement results fall between two extreme estimations.

– Excess of $k = 2$ coincidences (probably due to interactions in the shielding).

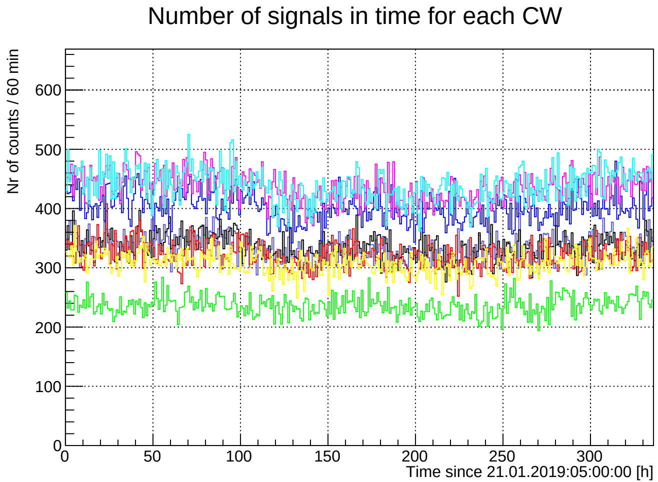
Energy of detected EAS – estimation from simulations



– Coincidence events with $k > 2$ is a sign of an EAS with energy in the $200 - 10^6$ TeV range.

– Higher energy cosmic-ray particles are too rare to be undoubtedly identified in this setup.

Differences between devices



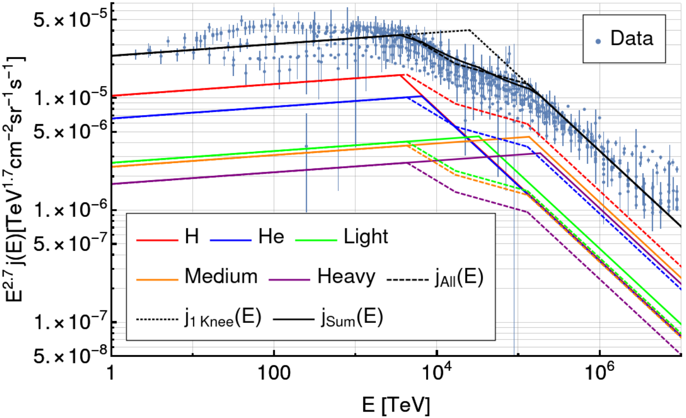
– Different colours represents different scintillators.

Conclusions

Summary:

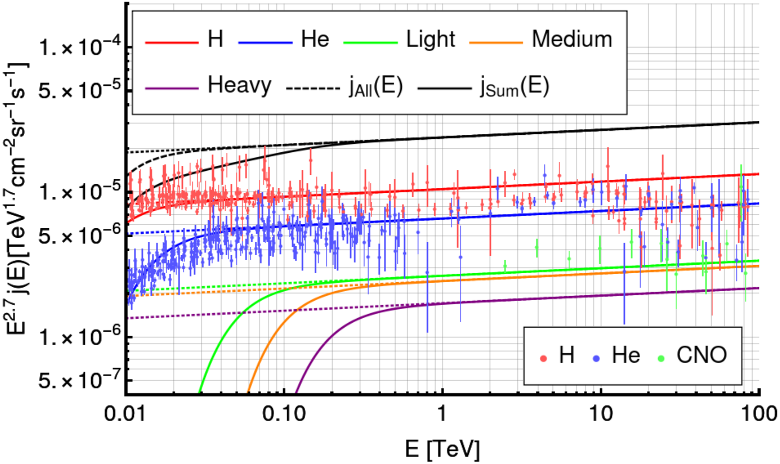
1. Events with 3 or more detectors triggered are caused by EAS.
2. Significant fraction of double coincidence events can be caused by a single cosmic-ray particle interacting in the enclosure and producing more particles.
3. Improvements in the design of detectors to make their efficiency better and more uniform are still possible.

Primary CR spectrum



Aartsen et al., 2013; Workman et al., 2022; Grieder, 2001; Maurin et al., 2023

Primary CR spectrum



Definition of symbols

Symbol	Definition
ρ_{part}	Density of particles
E	Energy of primary cosmic-ray particle
θ	Zenith angle
ϕ	Azimuthal angle
r	Distance from shower axis
N	Number of particles from EAS reaching ground
h	Altitude of observation
η_{part}	Efficiency of the detector for certain type of particles
p	Momentum of particles from EAS
$Q(n, k)$	Probability of triggering k out of n detectors in an array
j	Intensity of primary CR
j_0	Constant specific for each particle type of primary CR
γ	Spectral index

Parameters of estimation

Parameter	Value
η_{mes} – measured	Obtained from $I(\theta)$ measurement: 20 - 30%
$\eta_{\mu}(p)$ – simulated	100% for the whole p range
$\eta_{e}(p)$ – simulated	Rising quickly from 0 to 100% around $p = p_{th}$
$\eta_{\gamma}(p)$ – simulated	Between 3% and 20% depending on p and θ

Parameter	Minimal estimation	Maximal estimation
$\eta_{\mu}(p)$	20%	30%
$\eta_{e}(p)$	20% for $p_{th} \geq 0.03$ GeV	30% for $p_{th} \geq 0.007$ GeV
$\eta_{\gamma}(p)$	$20\% \times 3\% = 0.6\%$	$30\% \times 20\% = 6\%$
$j(E)$	Steep rigidity cut-off	No cut-off
Duty cycle	90%	95%

Proportions of efficiency for different detectors in the array:

1, 0.96, 0.69, 0.92, 0.52, 0.73, 0.76, 0.75

Bibliography I

- Aartsen, MG et al. (2013). "Measurement of the cosmic ray energy spectrum with IceTop-73". In: *Physical Review D* 88.4, p. 042004.
- Axani, SN, K Frankiewicz, and JM Conrad (2018). "CosmicWatch: The Desktop Muon Detector". In: *J. Instrum* 13, p. 03.
- Grieder, Peter KF (2001). *Cosmic rays at Earth*. Elsevier. Chap. 5.4.7, pp. 806,837.
- Homola, Piotr et al. (2020). "Cosmic-ray extremely distributed observatory". In: *Symmetry* 12.11, p. 1835.
- Maurin, David et al. (Oct. 2023). "A cosmic-ray database update: CRDB v4.1". In: *The European Physical Journal C* 83.10. ISSN: 1434-6052. DOI: 10.1140/epjc/s10052-023-12092-8. URL: http://dx.doi.org/10.1140/epjc/s10052-023-12092-8.
- Workman, R. L. et al. (2022). "Review of Particle Physics". In: *PTEP* 2022, p. 083C01. DOI: 10.1093/ptep/ptac097.