Cosmic Watch based detector array – measurements and simulations

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Plan of presentation

1. Motivation of the project.
2. Detector array.
3. Results of first measurements.
4. Simulations of scintillator detector.
5. Conclusions and prospects for future.

Meeting CREDO objectives

How to CREDO THE QUEST FOR THE UNEXPECTED ?

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How to CREDO ?

THE QUEST FOR THE UNEXPECTED

- Global cosmic ray studies.
- Cosmic Rays Ensembles hypothesis.
- Popularization and education.

Meeting CREDO objectives

How to CREDO THE QUEST FOR THE UNEXPECTED ?

- Global cosmic ray studies ⇒ correlations and anomalies in secondary cosmic rays flux.
- Cosmic Rays Ensembles hypothesis ⇒ searching for correlations between showers.
- Popularization and education ⇒ citizen science.

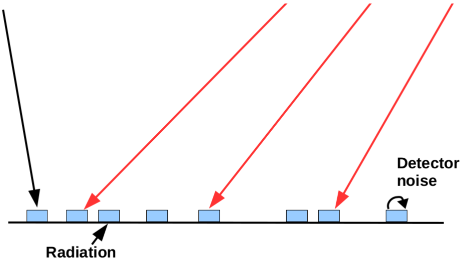
Creating a perfect detector

Our DREAM device characteristics:

- Big surface $\Rightarrow$ catches a lot of particles.
- Can identify EAS events.
- Good temporal resolution.
- Can distinguish types of particles.
- Low level of background signals.
- Can be constructed and operated by amateurs.
- Small.
- Inexpensive = affordable by individuals.
- Can operate for a very long period of time.

Creating a perfect detector

Detector array



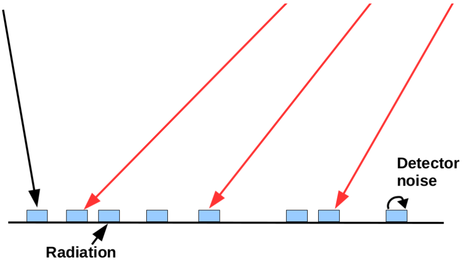
Cosmic Watch [1]:

- Small and relatively cheap.
- Easy to construct and operate.
- Tested design.

Flat coincidence system:

- Can identify EAS events.
- Easy to implement.
- Does not require a lot of space.
- Can be easily expanded.

Detector array



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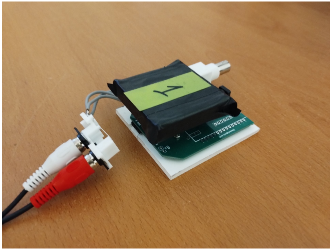
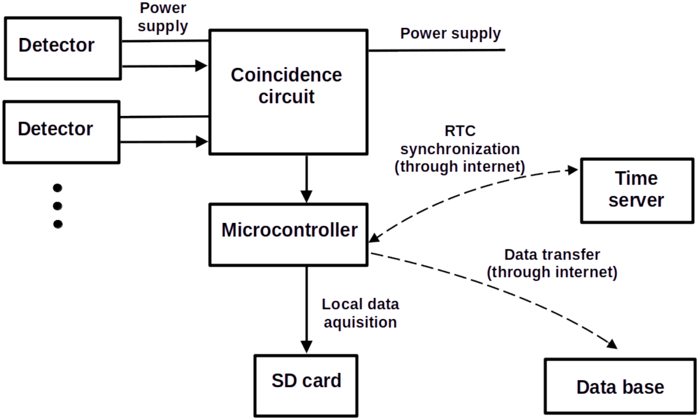


Creating a real detector

Our REAL device characteristics:

- ~~Big~~ Medium surface ⇒ catches ~~a lot of particles~~ around 1–2 particle per s.
- Can identify EAS events.
- Good temporal resolution = dozens of μs or better.
- ~~Can distinguish types of particles.~~
- Relatively low level of background signals.
- Can be constructed and operated by amateurs.
- Small.
- Inexpensive – affordable by institutions and some individuals.
- Can operate for a very long period of time.

Detector array – electronics



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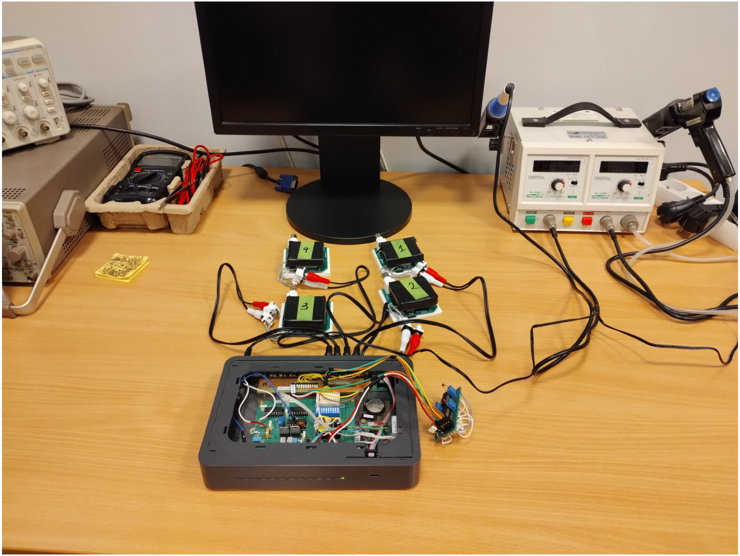

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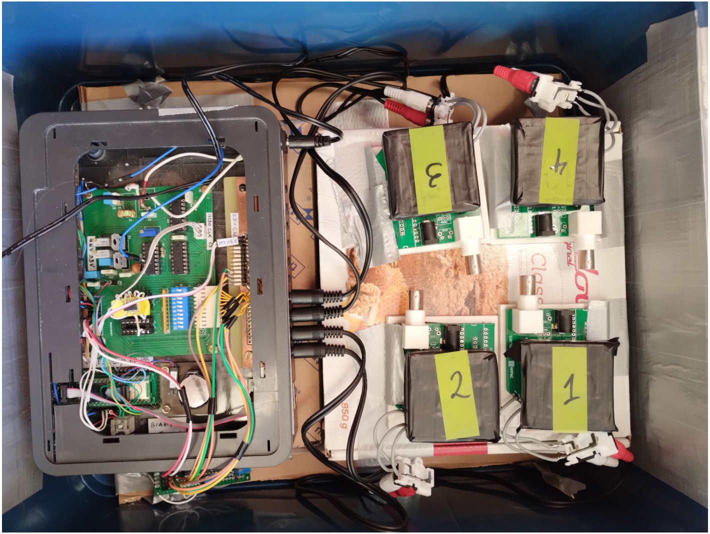
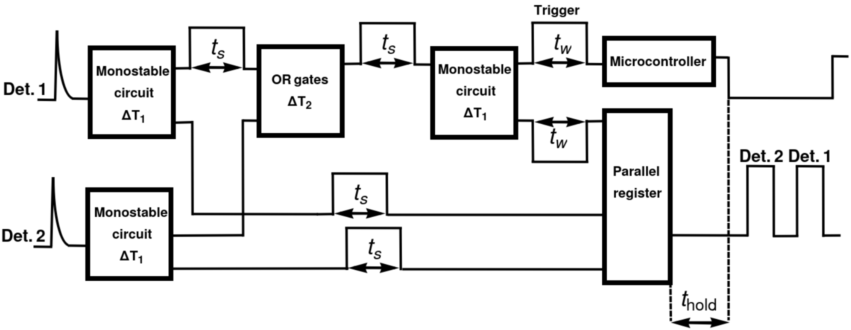


Detector array – signal processing



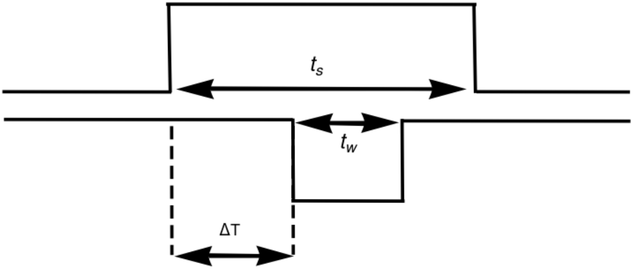
t_s – signal length.

t_w – window length.

t_{hold} – time after which data is read.

$\Delta T_{1,2}$ – delays.

Detector array – signal processing



$$\Delta T = \Delta T_1 + \Delta T_2.$$
$$t_s > t_w + \Delta T = t_0$$

t_0 – real length of coincidence window. Maximum time interval between two particles to be in coincidence.

Detector array – data collection

Currently:

- Only local data acquisition on SD card.
- Very slow ≈ 0.015 s.

Future:

- Faster local data acquisition.
- Data send directly to the server.
- Both ethernet and Wi-Fi usage.

Detector array – data format

Example of current data format:

Day	Month	Year	Hour	Minute	Second	Temp.(degC)	P(hPa)	Input 1	Input 2	Input 3	Input 4
02	01	2024	14	43	40.99056	27.80	1004.91	0	0	1	0
02	01	2024	14	43	42.31707	27.99	1004.91	0	1	0	0
02	01	2024	14	43	43.58618	27.62	1005.79	0	0	1	0
02	01	2024	14	43	44.10784	27.99	1004.39	0	0	0	1
02	01	2024	14	43	45.29840	27.80	1004.39	0	0	0	1
02	01	2024	14	43	45.40017	27.99	1004.91	0	1	0	0
02	01	2024	14	43	45.42907	27.99	1005.79	0	0	0	1

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02	01	2024	14	44	13.01129	27.80	1006.31	1	0	0	0
02	01	2024	14	44	13.05172	27.99	1002.98	0	1	0	0
02	01	2024	14	44	13.28063	27.99	1002.46	0	0	1	0
02	01	2024	14	44	13.56262	27.62	1004.39	0	1	0	1
02	01	2024	14	44	14.10897	27.99	1004.39	1	0	0	0
02	01	2024	14	44	14.50643	27.80	1005.79	0	0	0	1

Detector array – prize

Estimated costs of components:

1. One simplified Cosmic Watch: $\approx$ **125 USD**
2. Master unit: $\approx$ **150 USD**
3. Equipment for outdoors measurement: $<$ **50 USD**

For target array of 8 detectors:

$<$ **1200 USD + assembly costs**

Measurements – different conditions

Place where first measurement was conducted – ground floor in 5 storage building, not many windows.

Measurements – different conditions

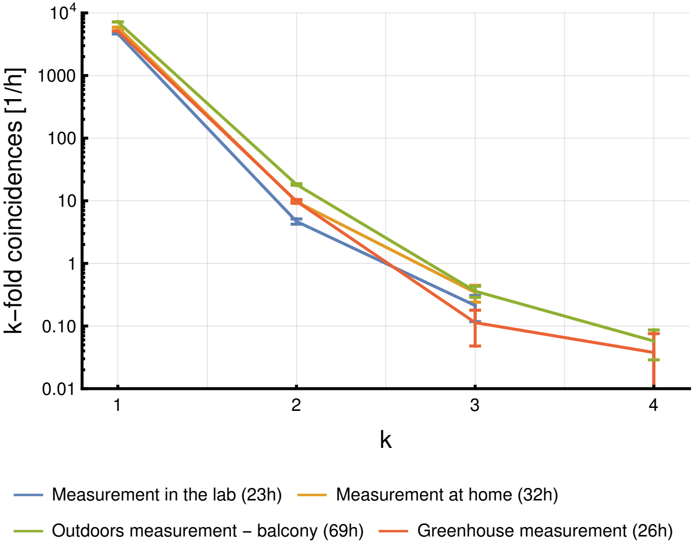
Place where second measurement was conducted – 1st floor in 5 storage building, more windows. Third measurement was conducted on the balcony, around 2 m from here.

Measurements – different conditions

Place where fourth measurement was conducted – greenhouse at the top of the building.

Measurements – different conditions

Effect of different conditions on the results of measurement:



Measurements – different conditions

Effect of different conditions on the results of measurement:

[1/h]	**Lab**	**Home**	**Balcony**	**Greenhouse**
$k = 1$	4630	5880	7170	5150
$k = 2$	4.7	9.7	18.2	9.8

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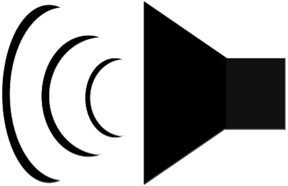
Conclusions:

Measurements conditions have significant impact on the results

Measurements – sonification of data [2]

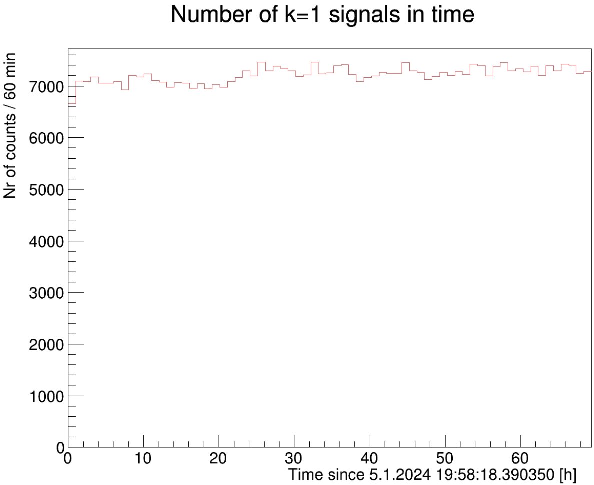
Listen to the data.



Can you hear any pattern?

Measurements – interesting behaviour

Little increase in frequency of signals observed in outdoors measurement:



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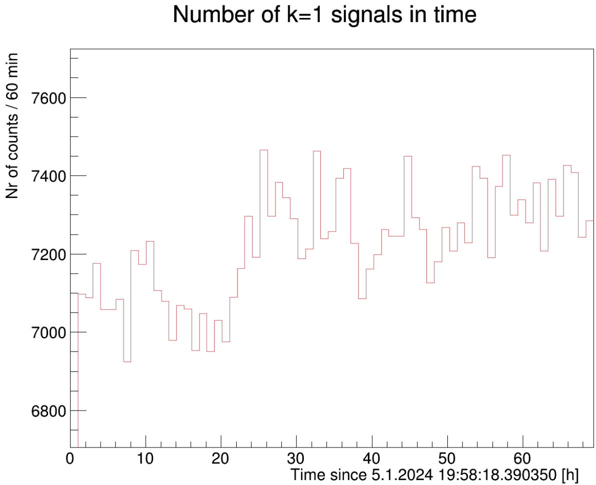

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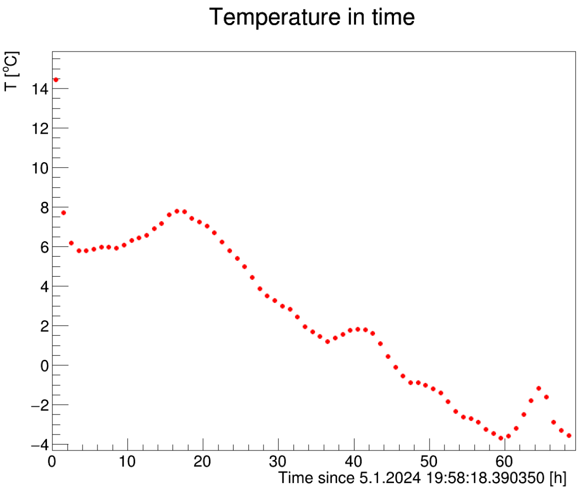

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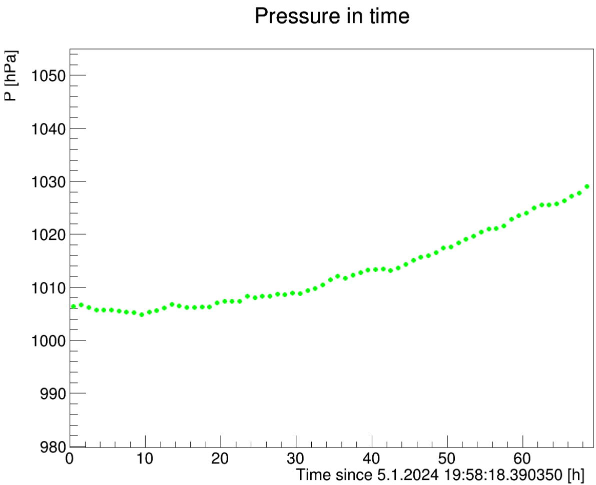

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To answer this we should...

- ...simulate detector's response to interaction with cosmic rays,
- ...simulate secondary cosmic rays with CORSIKA (not ready to present yet),
- ...and compare estimations with results of measurement (not ready to present yet).

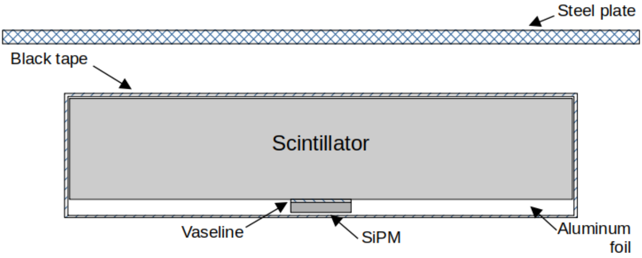
Simulations of detectors sensitivity to CR

Purpose:
Estimate sensitivity of used detectors, η, to different secondary cosmic rays. Study effects of different shielding above the detector.

Used software [3–5]:
Geant4 – enables full control over geometry of the experiment, composition of its elements, includes physics of particles interactions with media and is easy to operate.

Considered particles:
Muons, electrons & positrons, and photons.

Simulations – detector's geometry



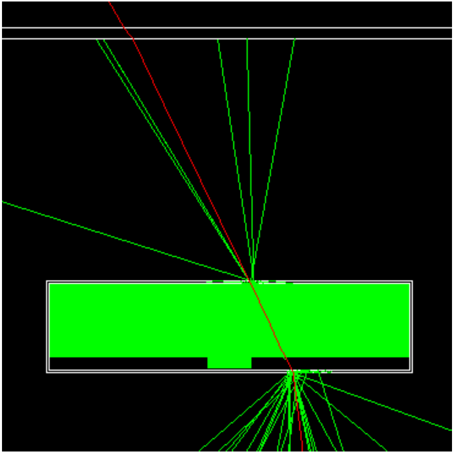
- Stainless steel plate: d = 1.5 mm
- Aluminum foil: d = 0.14 mm, reflectivity = 85 %
- Black tape: d = 0.36 mm
- Plastic scintillator: 5 × 5 × 1 cm
- Vaseline: 0.6 mm
- SiPM: 0.6 × 0.6 × 0.1 cm

Simulations – detector's composition [6]

	BC408 scintillator	Al foil	Black tape	Steel	SiPM	Vaseline
Density [g cm^{-3}]	1.032	2.7	1.28	7.9	2.329	0.82
Composition	H, C	Al	H, C, Cl	Fe, Cr, Ni, C	Si	H, C, N
Ratio of elements % of elements	11:10	1	3:2:1	 70.87, 20, 9.25, 0.06	1	15:15:1
Refractive index ($300 < \lambda < 950$ nm)	1.58	1.44	1.54	$n(\lambda)$ (1.65 – 2.95)	1.59	1.467
Absorption index [cm^{-1}]	0.001	966850	0.69339	1606300	–	≈ 0

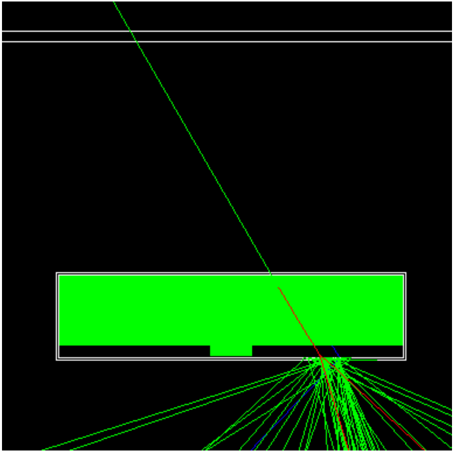
Simulations – visualisation

Exemplary events visualisation:
e^-, $\theta = 30^\circ$, $\epsilon = 0.01$ GeV



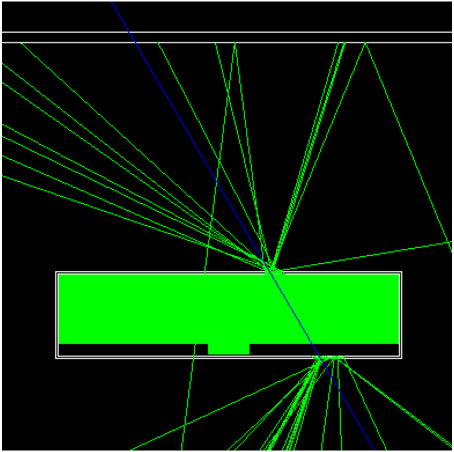
Simulations – visualisation

Exemplary events visualisation:
γ, $\theta = 30^\circ$, $\epsilon = 0.03$ GeV



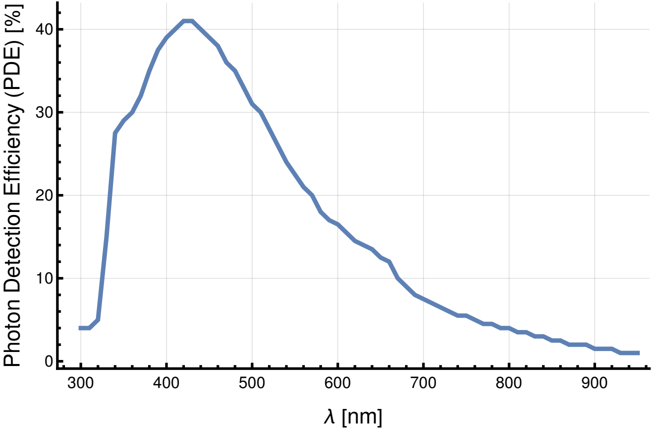
Simulations – visualisation

Exemplary events visualisation:
mu^+, $\theta = 30^\circ$, $\epsilon = 1$ GeV



Simulations – SiPM sensitivity

PDE – Photon Detection Efficiency



Simulations – calculations of signals amplitude

Simulations output:

N_{ph} - number of photons detected by SiPM (after applying PDE function).

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Amplitude of produced signal:

$$V_s = \Delta V \cdot c_p \cdot M \left(1 - \exp\left(-\frac{N_{ph}}{M}\right)\right). \qquad (1)$$

c_p – percent of SiPM surface covered by microcells, M – number of microcells on SiPM.

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Microcell discharge voltage:

$$\Delta V = \frac{G(V_{SiPM}) \cdot q}{C}, \tag{2}$$

$G(V_{SiPM})$ – gain, q – electron charge, C – microcell's electrical capacity.

Simulations – local sensitivity

Sensitivity of our detector:

$$\eta = \frac{n(V_s > V_{min})}{n}, \tag{3}$$

n - number of simulated events, V_{min} – minimal amplitude that can be processed by electronics (after amplification).

Sensitivity variability:

$$\eta = \eta(x_{det}, y_{det}, \theta, \phi). \tag{4}$$

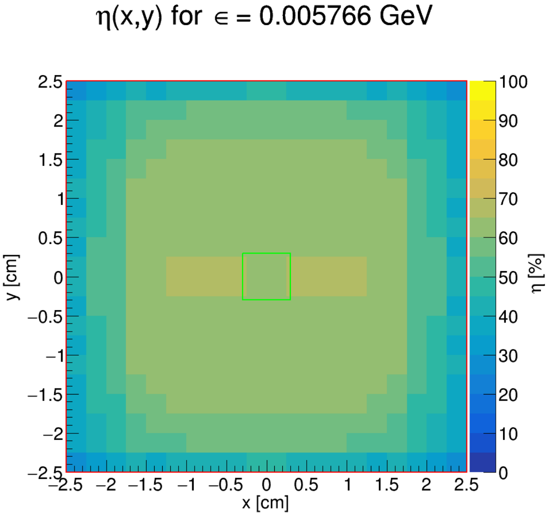
Effective sensitivity:

$$\eta_{eff} = \frac{1}{A} \int_A \eta(x, y)_{\theta,\phi} \, dx \, dy, \tag{5}$$

A – detector's area of the surface.

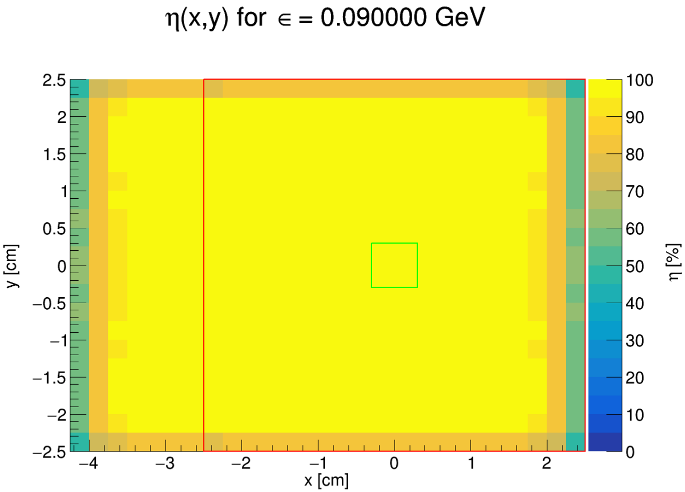
Simulations – mapping detector

Map of detector's sensitivity: e^-, $\theta = 0°$, $\phi = 0°$



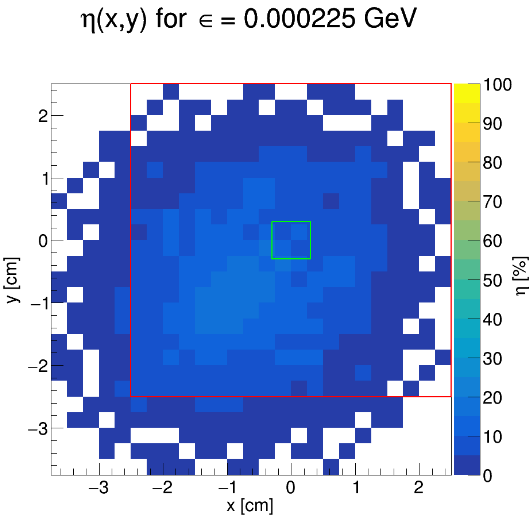
Simulations – mapping detector

Map of detector's sensitivity: mu$^+$, $\theta = 60°$, $\phi = 0°$



Simulations – mapping detector

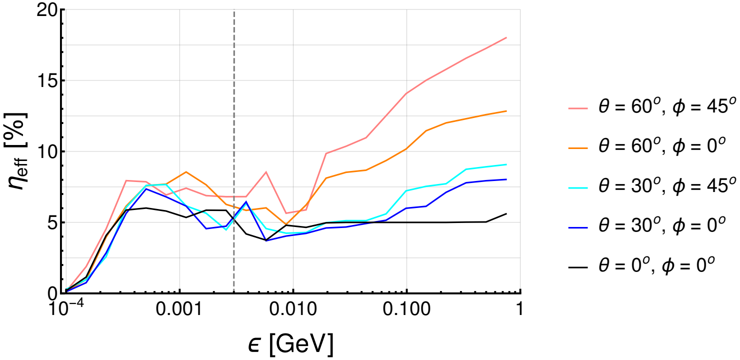
Map of detector's sensitivity: γ, $\theta = 60°$, $\phi = 45°$



Simulations – effective sensitivity

Photons:

Sensitivity to photons increase with inclination angle and does not drop to 0 below simulations threshold.

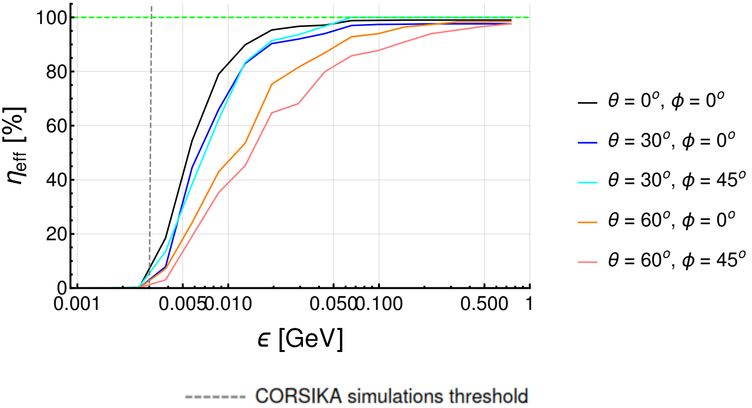


------- CORSIKA simulations threshold

Simulations – effective sensitivity

Electrons:

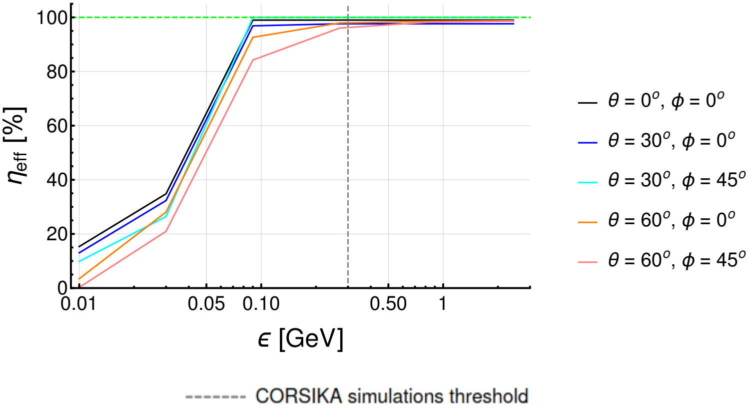
Sensitivity to photons drops with inclination angle, below simulations threshold is close to none and reaches maximum at certain value.



Simulations – effective sensitivity

Muons:

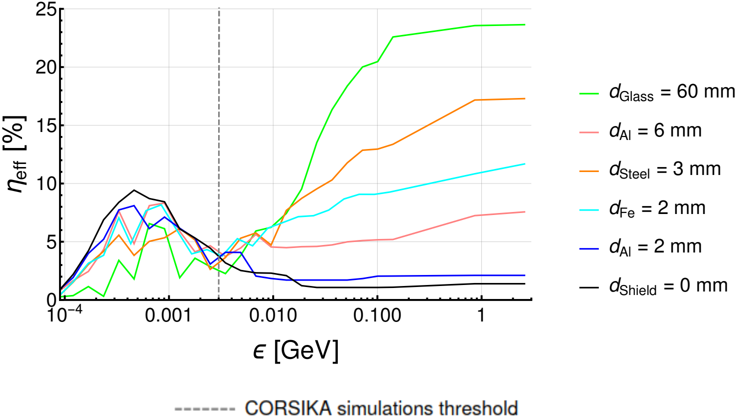
Sensitivity to photons drops slightly with inclination angle and reaches maximum at value slightly lower than simulations threshold.



Simulations – different shielding

Photons:

Different thickness and kind of shielding has huge impact on the sensitivity.



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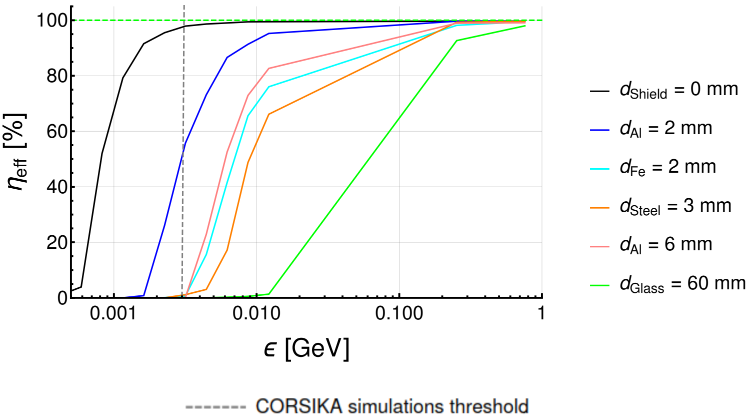

Conclusions – measurements

1. Frequency of signals is sensitive to measurements conditions – everything above detectors.
2. Frequency is signals and coincidence events is relatively high.
3. Detector is able to safely operate in difficult weather conditions.

Conclusions – simulations

1. Our scintillator detector is mostly sesnitive to muons and high energy electrons.
2. Sensitivity to photons is of the order of 10% – low but not negligible.
3. Detector's sensititvity is highly sensitive to the shielding which particles have to penetrate.
4. Effective sensitivity changes with increasing inclination angle of arriving particles.

Future plans

1. Construct second array consisting of 8 detectors.
2. Perform long term outdoors measurements.
3. Optimize detectors software.
4. Standardise data format and develop remote data acquisition.
5. Prepare full documentation of the project and publish it.

Thank you for your attention!

Bibliografia I

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