CREDO

THE QUEST FOR THE UNEXPECTED

INSTYTUT FIZYKI JĄDROWEJ
IM. HENRYKA NIEWODNICZAŃSKIEGO
POLSKIEJ AKADEMII NAUK

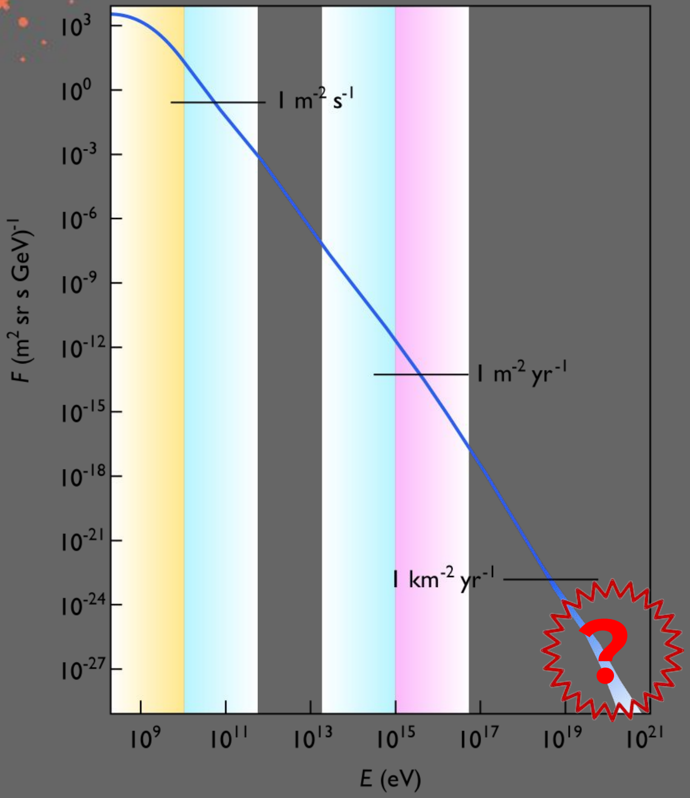
The **C**osmic-**R**ay **E**xtremely **D**istributed **O**bservatory
A new approach to cosmic-ray physics

By *Kévin Almeida Cheminant for the CREDO Collaboration*

Instytut Fizyki Jądrowej PAN, Krakow, Poland

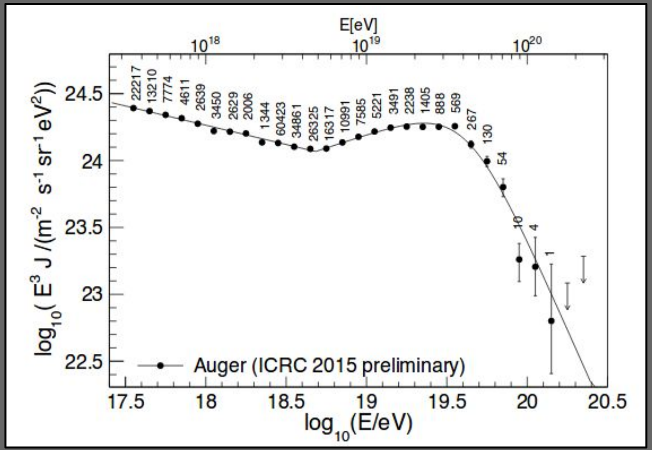
Particle Astrophysics in Poland - May 20th- 21st - *Warsaw, Poland*

Introduction: a bit of context



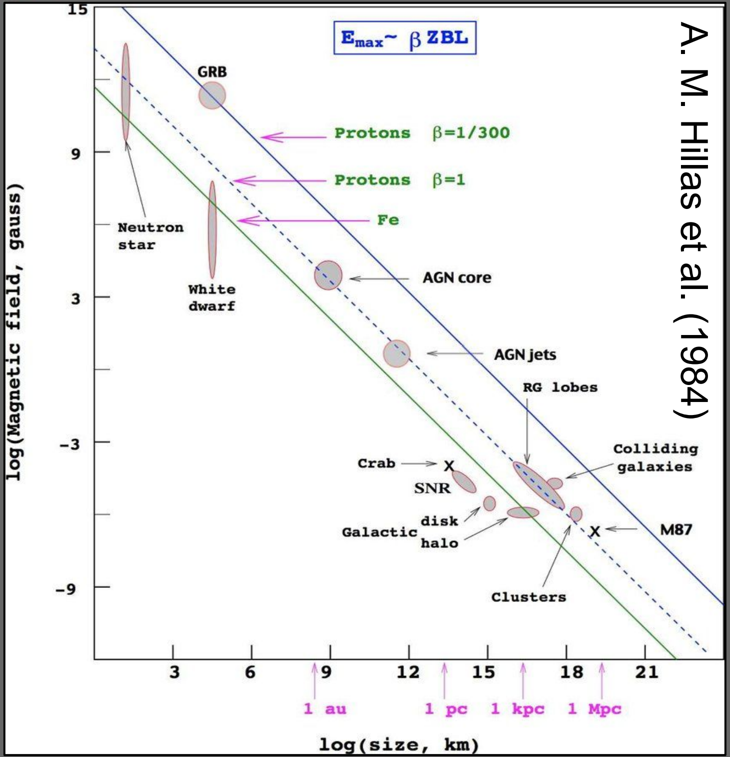
Ultra-high energy cosmic-rays (UHECRs)

- ➢ What's their composition?
- ➢ Where do they come from?
- ➢ How do they reach such tremendous energies?



Introduction: a bit of context

Classic bottom-up acceleration

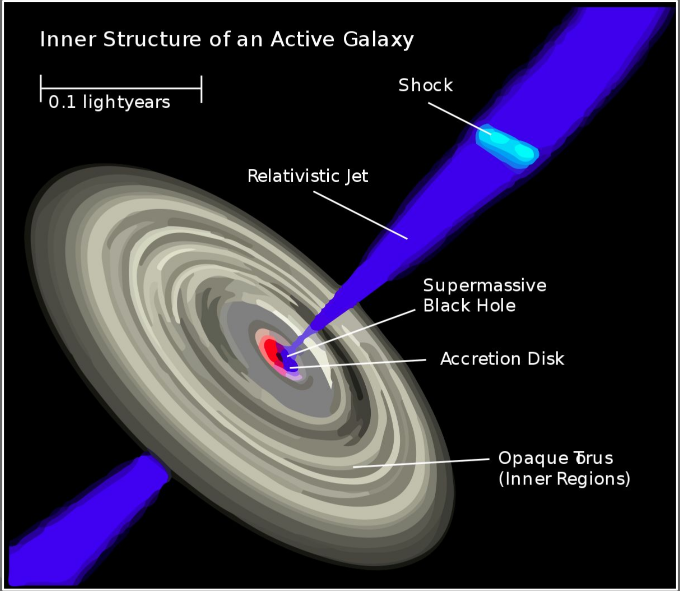


A. M. Hillas et al. (1984)

Introduction: a bit of context

Classic bottom-up acceleration

Observation of 290 TeV neutrino correlated to the blazar **TXS 0506+056** by IceCube strengthen such scenario!



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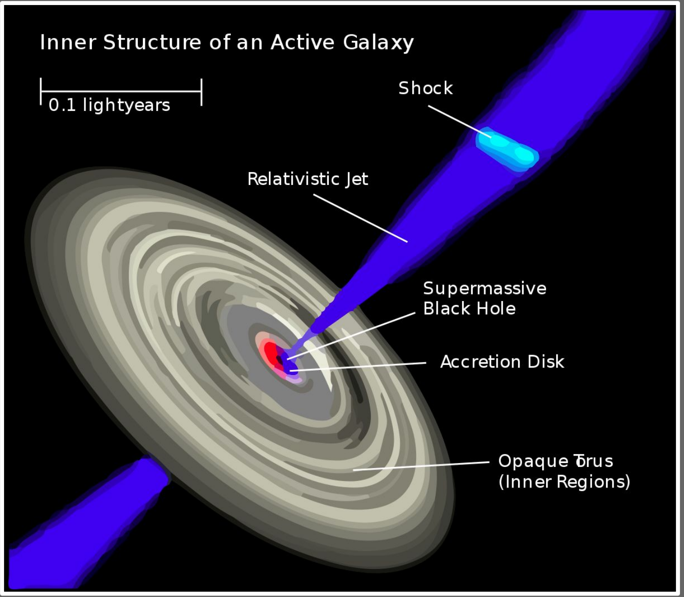


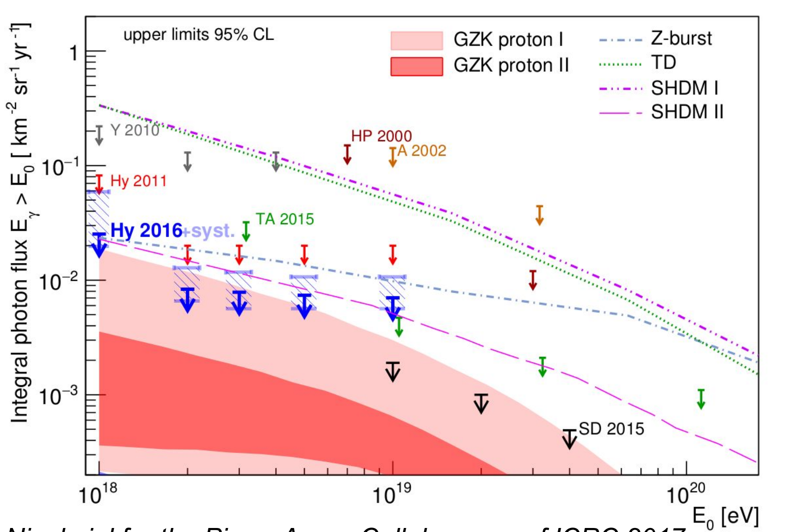
Decay or annihilation of supermassive particles (top-down mechanism)

The decay of massive relics ($M_X > 10^{11}$ GeV) from the Early Universe may result in the production of **UHECRs** & **UHE photons.**

- ➢ *X* must decay in recent cosmological epoch or at distances < 100 Mpc from Earth.
- ➢ *X* must be sufficiently massive (> 10^{11} GeV) to allow the decay products to reach UHEs.
- ➢ Density and decay rate must be large enough to generate a flux of decay products that can be detected.

Introduction: a bit of context

UHE photons are expected from the *decay of super massive particles* and from the GZK effect *(UHECRs interactions with radiation field).*



Niechciol for the Pierre Auger Collab., proc. of ICRC 2017

Introduction: a bit of context

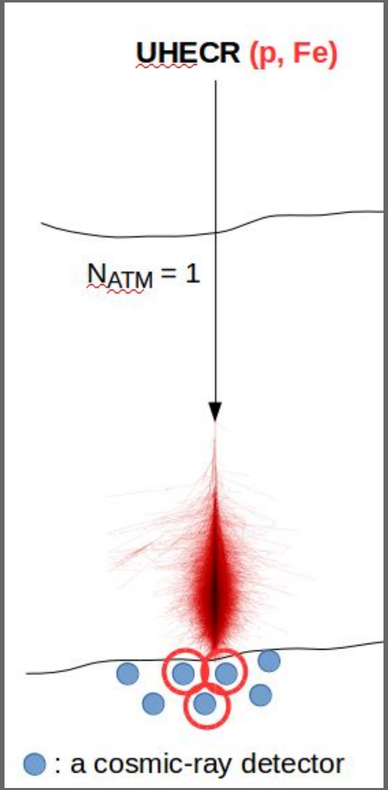
$$\gamma_{UHE} \xrightarrow{\text{no interactions / screening}} \text{Earth}$$

NOT OBSERVED

$$\gamma_{UHE} \xrightarrow[\text{screening, ...}]{\text{unexpected interactions,}} \boxed{\text{ELECTROMAGNETIC CASCADES (SUPER-PRESHOWERS)}} \longrightarrow \text{Earth}$$

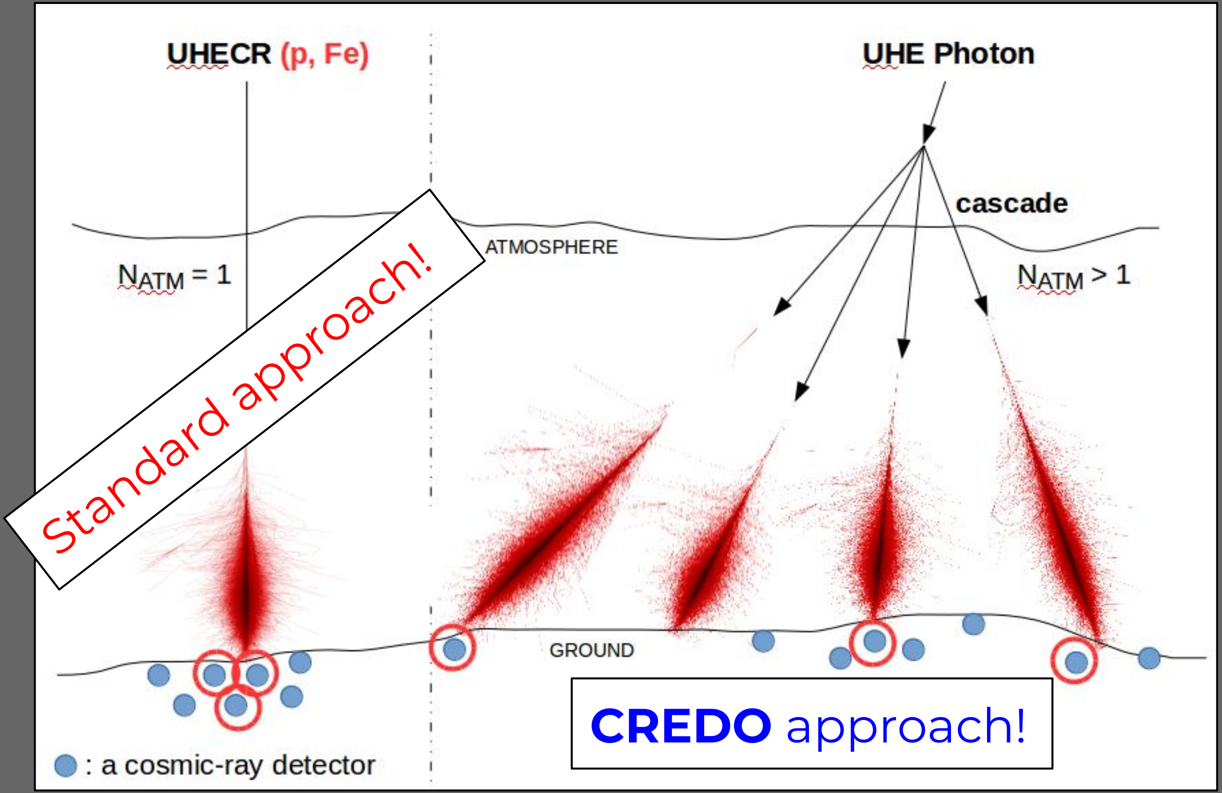
INVESTIGATED BY **CREDO**

Super-preshowers



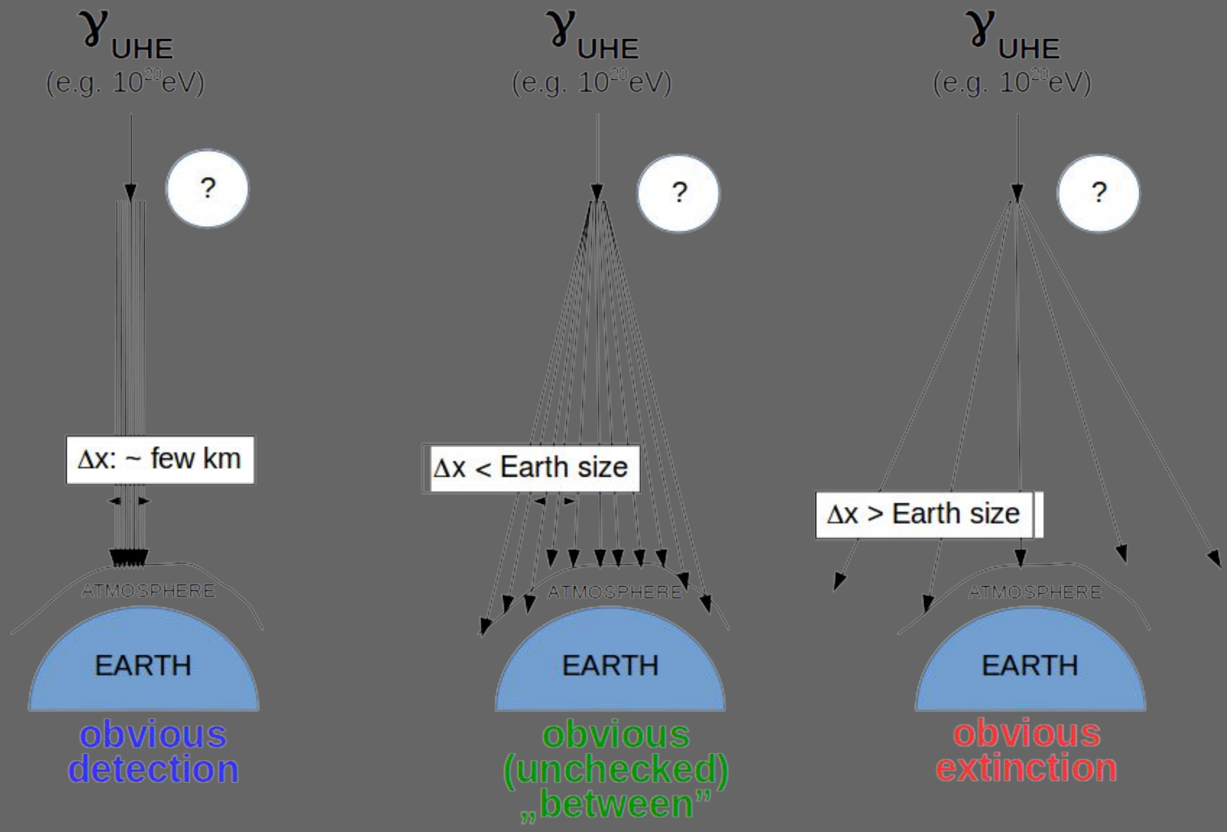
A **single particle** hits the atmosphere and produces a **single air shower** that can be reconstructed by detectors on the ground via various channels of observation, such as *Cherenkov radiation* or *fluorescence light*.

Introduction: a bit of context



Super-preshowers

Multiple scenarios are possible based on the <u>distance</u> between the interaction point and the Earth's atmosphere, and the <u>nature of the interaction</u>.



- ➢ **Different observation techniques** can be used for each scenario.

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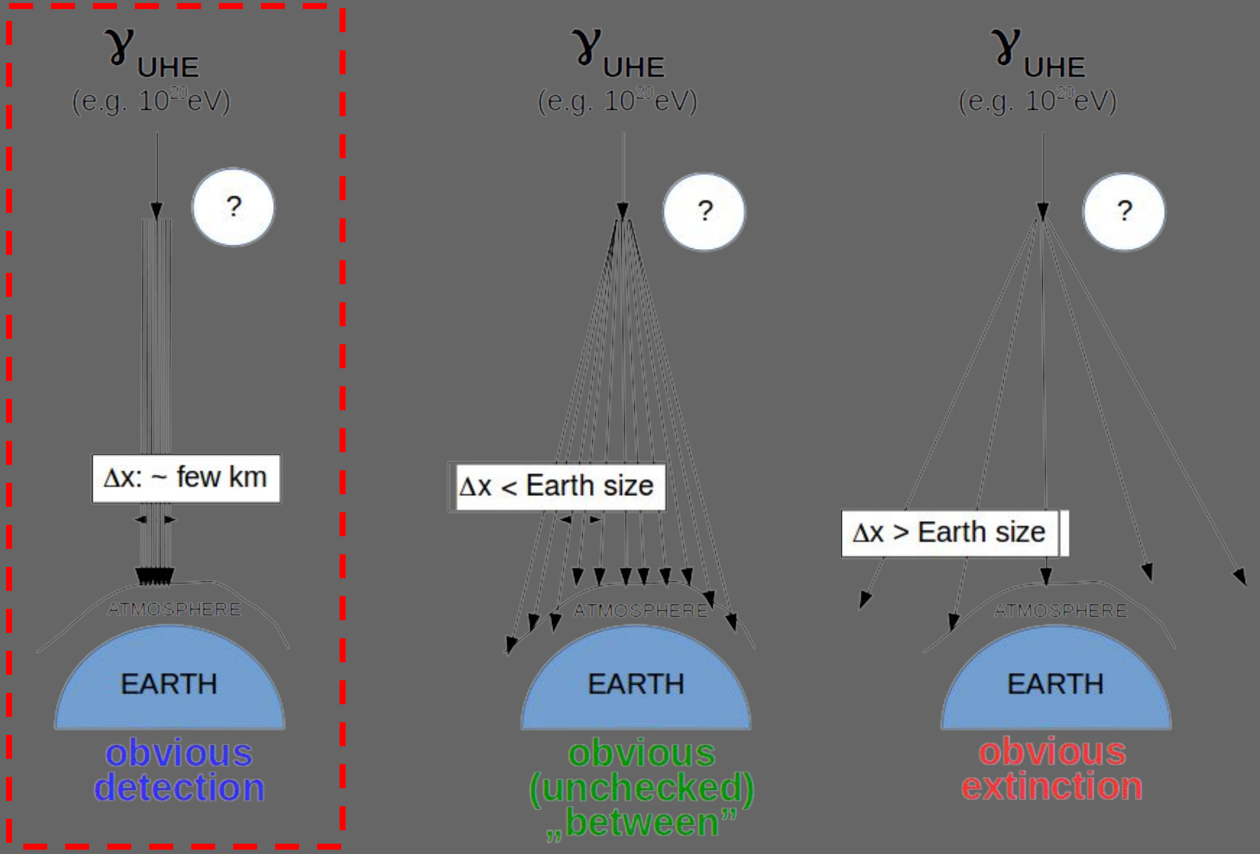
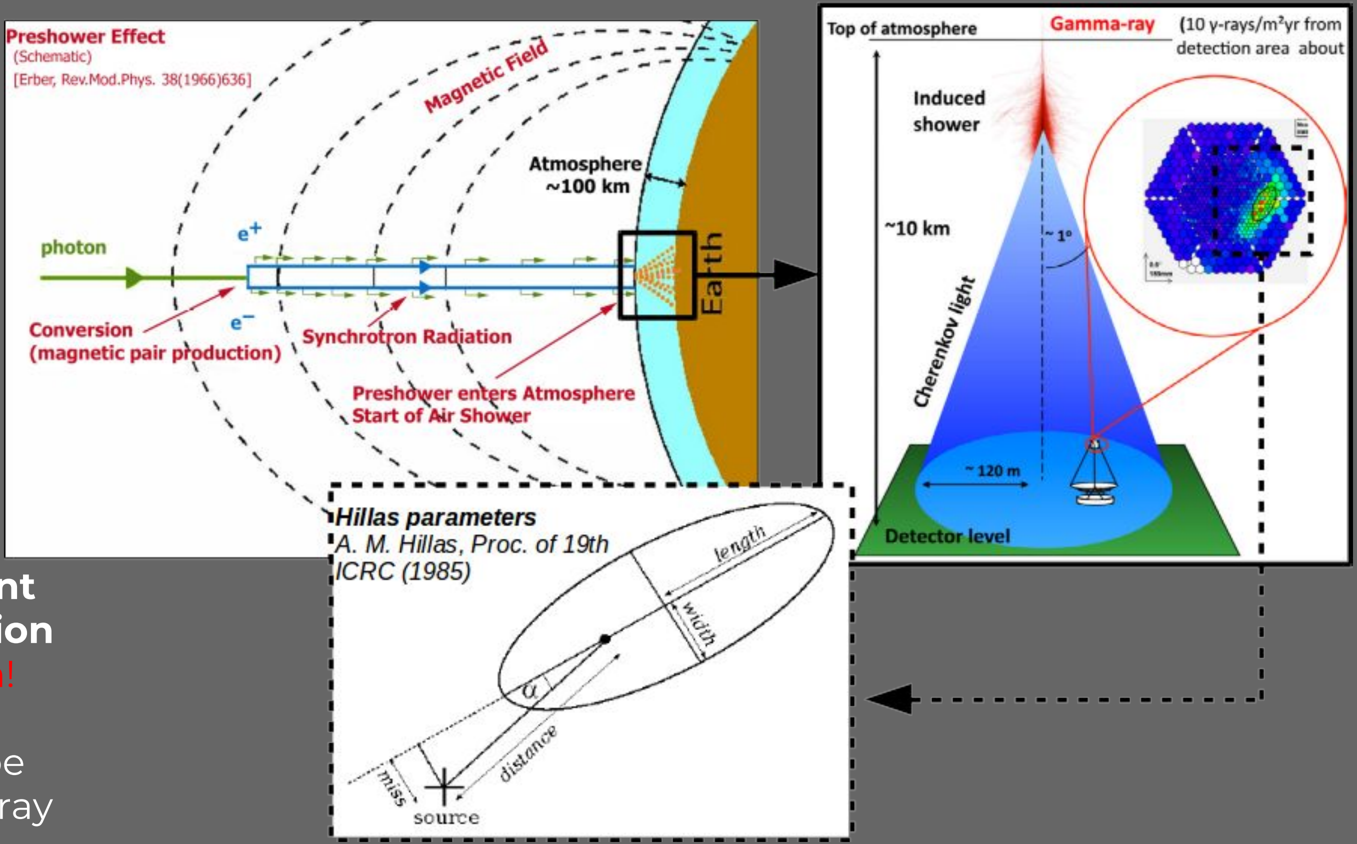
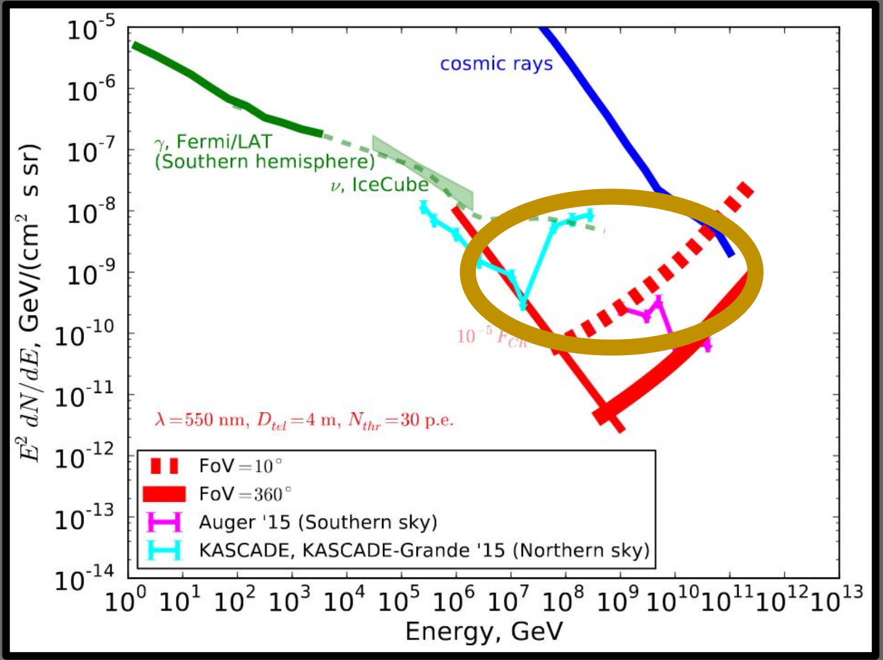


Preshower effect

- Preshower effect as an **indirect proof of UHE photons existence**.
- <u>Nearly-horizontal observation mode</u> for gamma-ray telescopes
- Allows to retrieve **excellent gamma/hadron separation** → non-standard approach!
- **Pioneer study** that can be applied to most gamma-ray telescopes array.



Preshower effect



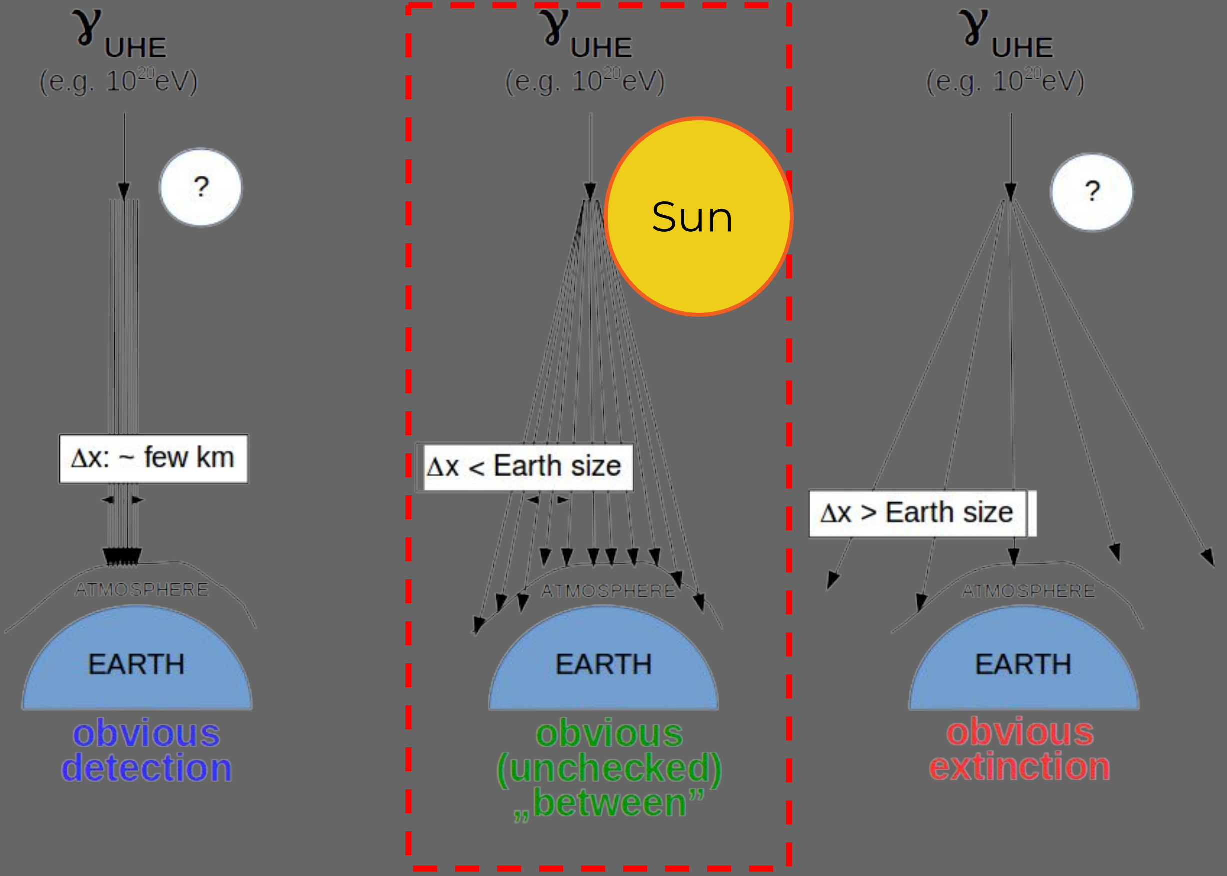
A. Neronov et al., Phys. Rev (2016), astro-ph/1610.01794

- **Various model** of ultra-high energy photons emission can be tested.
- **New limits** can be obtained on the ultra-high energy photon flux!
- **Sensitivities** to UHE photons close to KASCADE and Pierre Auger Observatory.
- Preshower effect observed by gamma-ray telescopes in the nearly horizontal direction could allow to reach **sensitivities to UHE photons close to KASCADE and Pierre Auger Observatory**!

Super-Preshower near the Sun

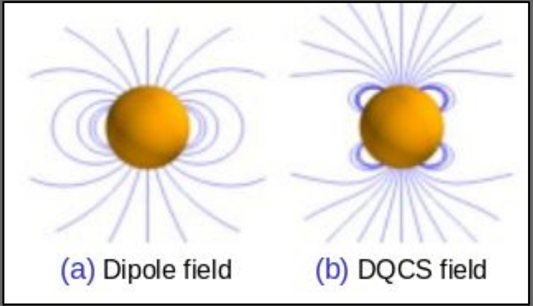
- First calculations by *W. Bednarek* (1999): low energies not treated → extent ~ **tens of km** at the top of the atmosphere.

- New simulations by *N. Dhital* (2019 - arXiv:1811.10334): all energy spectrum → extent ~ **thousands of km** at the top of the atmosphere.



Super-Preshower near the Sun

➢ Cascade development studied using Monte Carlo simulations with two solar magnetic field models.



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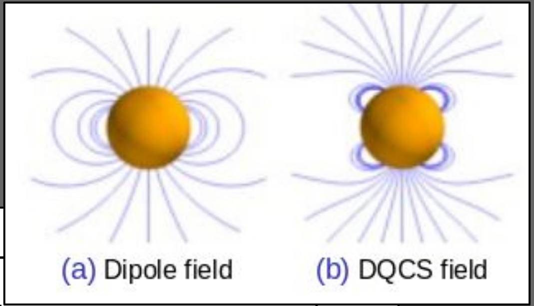

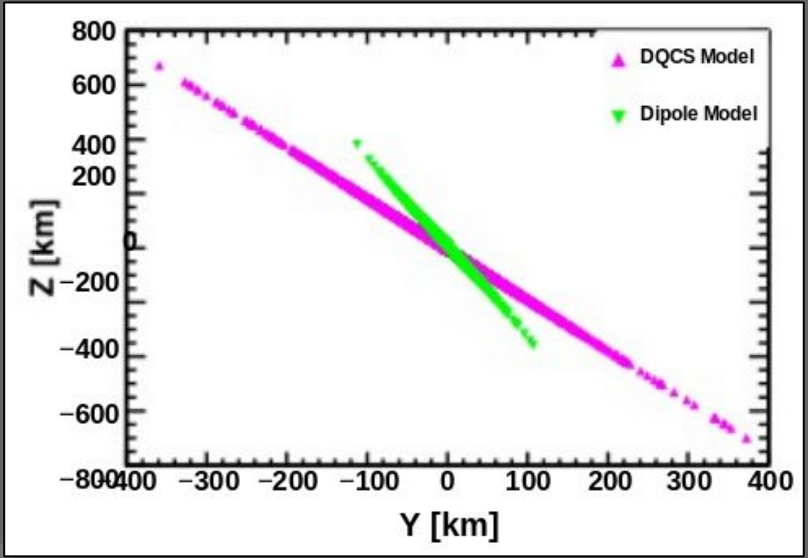

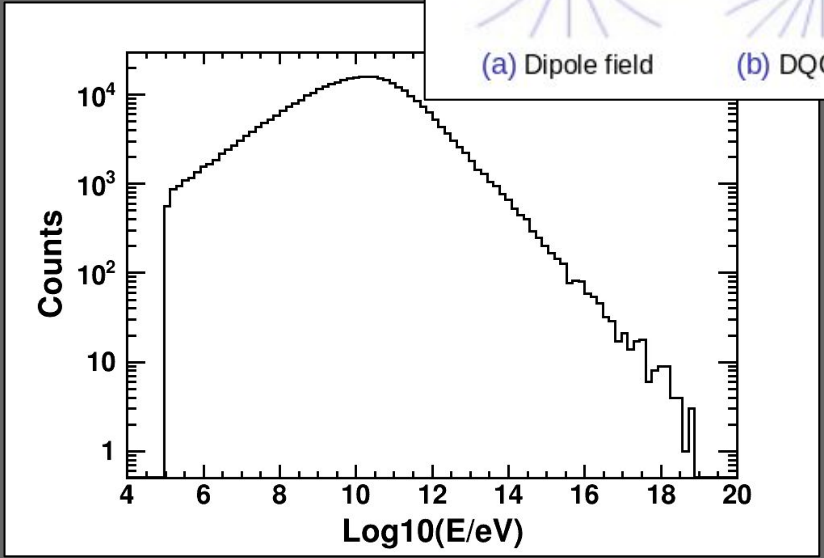

*Distribution of photons with **energies > 10^{12} eV** arriving at the top of the atmosphere. Primary photon (**100 EeV**) is directed towards Earth such that the position of the closest approach has **heliocentric latitude 45° and impact parameter 3R☉**.*

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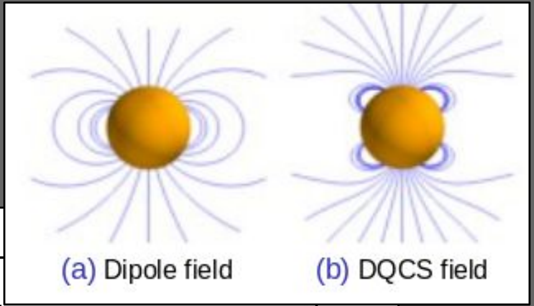
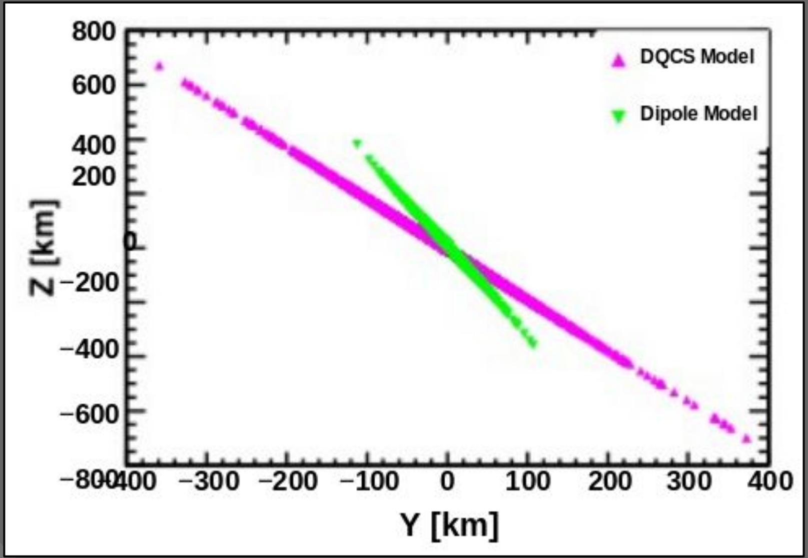
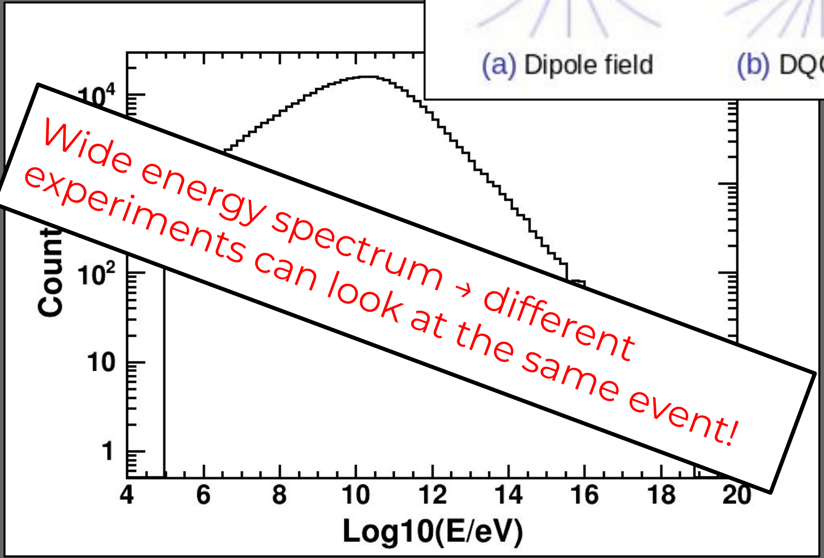




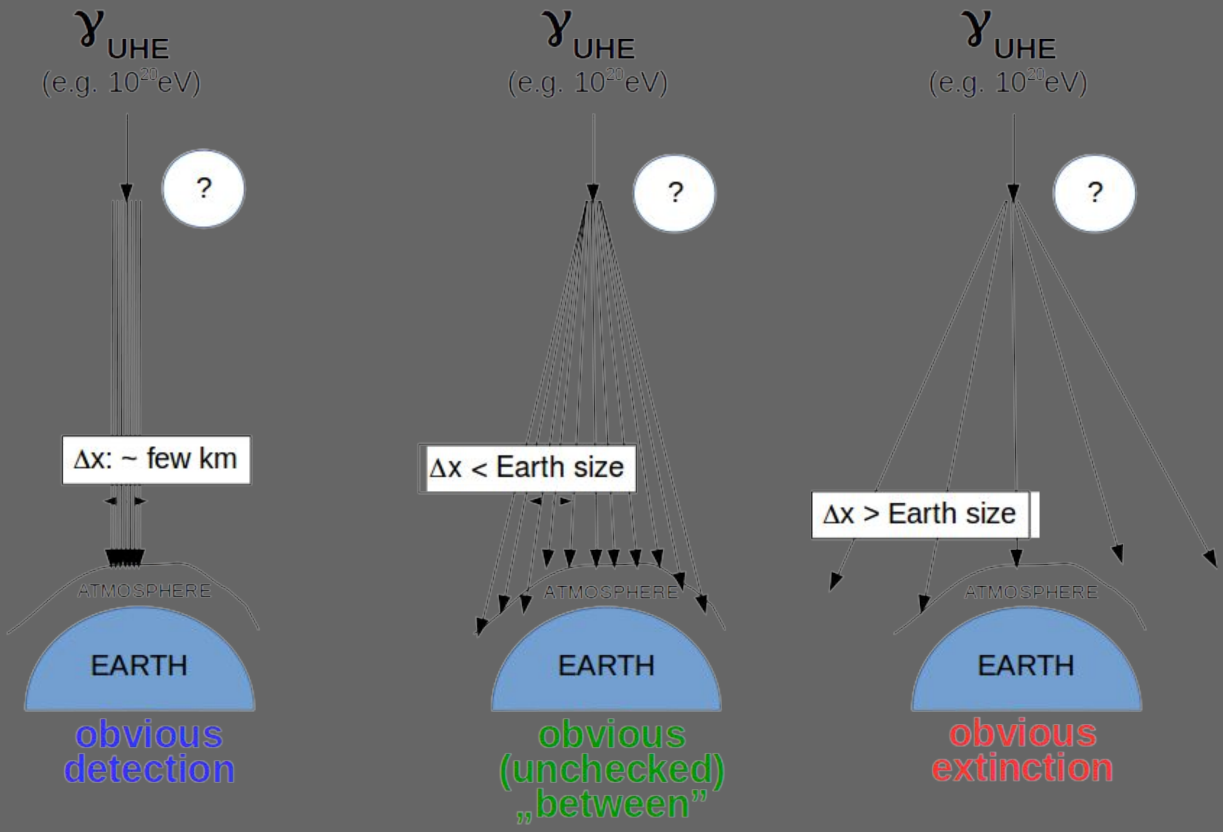


Wide energy spectrum → different experiments can look at the same event!

*Distribution of photons with **energies > 10^{12} eV** arriving at the top of the atmosphere. Primary photon (**100 EeV**) is directed towards Earth such that the position of the closest approach has **heliocentric latitude 45° and impact parameter 3R⊙**.*

Extremely **D**istributed **O**bservatory

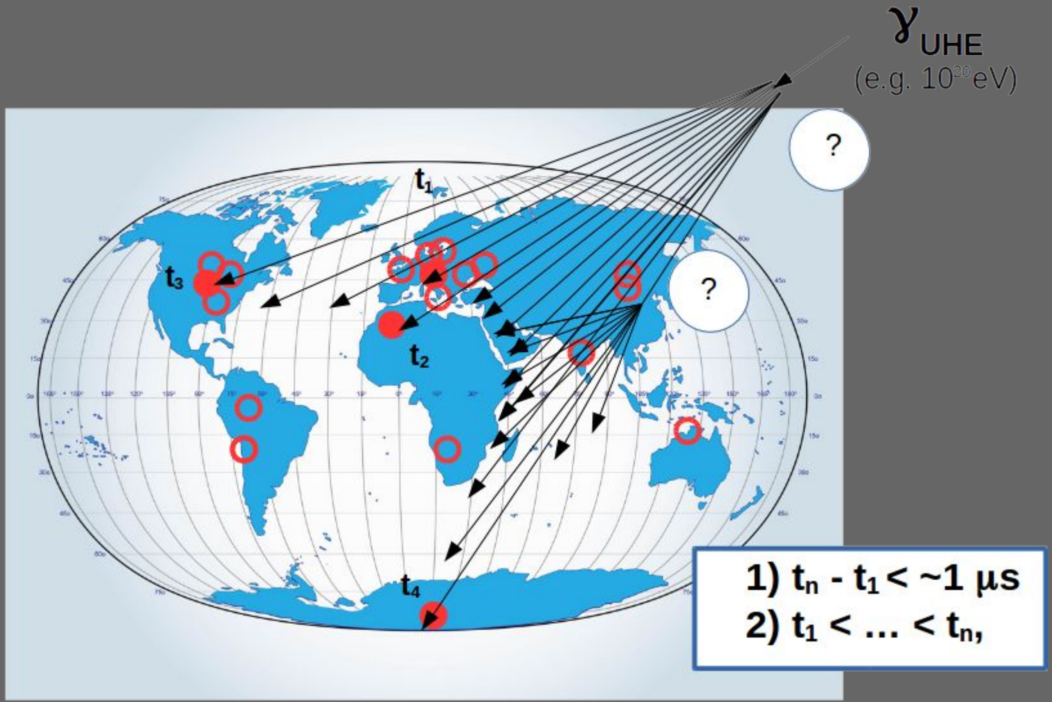
How can we search for extremely extended events?



Extremely **D**istributed **O**bservatory

<u>**CREDO**’s main idea:</u> creating a global network of particle detectors!

How?...



Extremely Distributed Observatory

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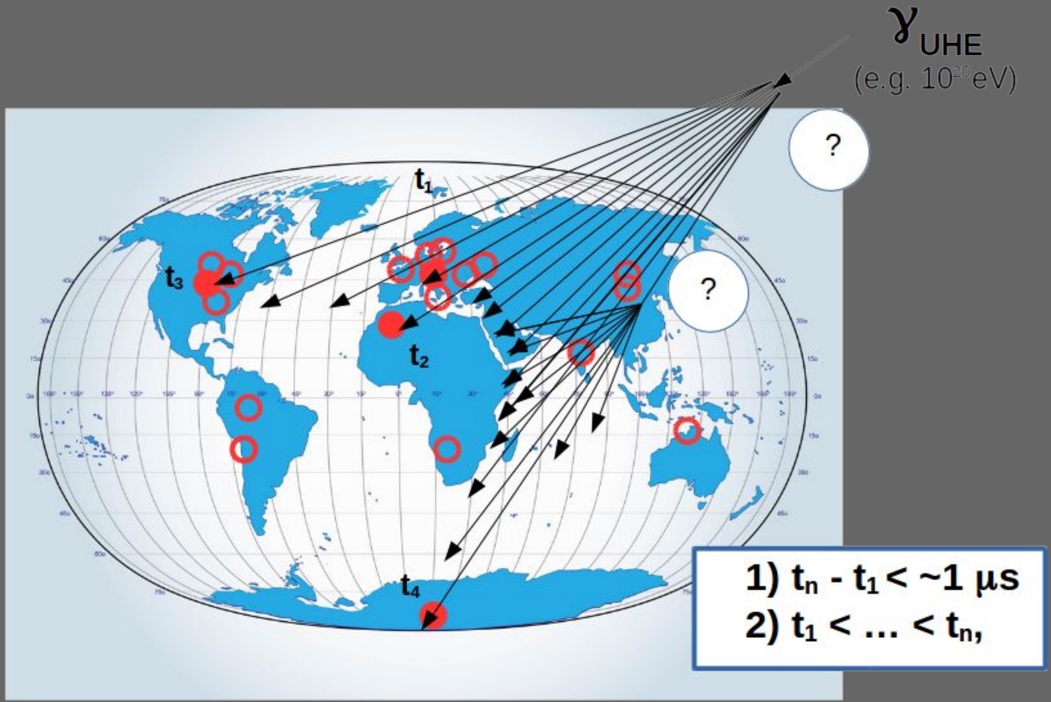


+ connecting **existing observatories** to the network

Extremely **D**istributed **O**bservatory

Principle: particles hitting the camera sensors and triggering pixels by depositing energy.

- ➢ Detections are filtered to remove artifacts and stored in a central database (Cyfronet AGH-UST).
- ➢ Analysis are run to search for peculiar signal signatures.
- ➢ Users can access the data they collected and see the results from the analysis run on their data.

STIMULATES CITIZEN SCIENCE !

Extremely **D**istributed **O**bservatory

Location of users since the launch

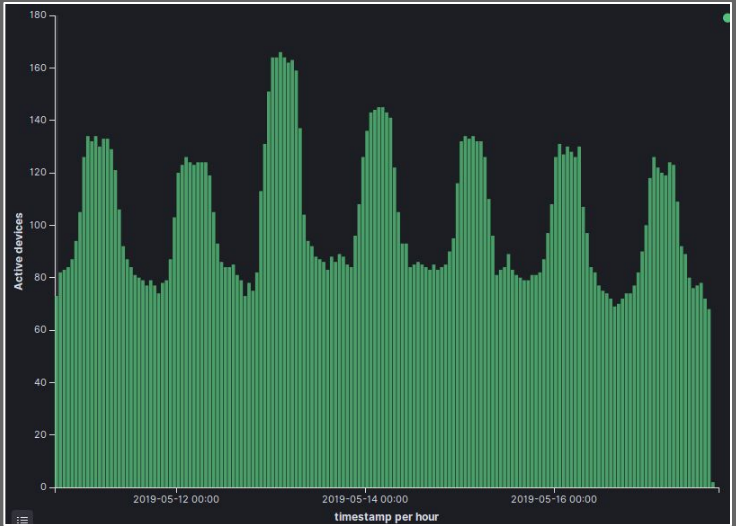
Statistics from launch to May 17th 2019

- ~**2 917 742 detections**
- App running sums up to **958 years** looking for particles
- **7395 users** with at least 1 detections
- **10472 devices**
- **2533 teams**

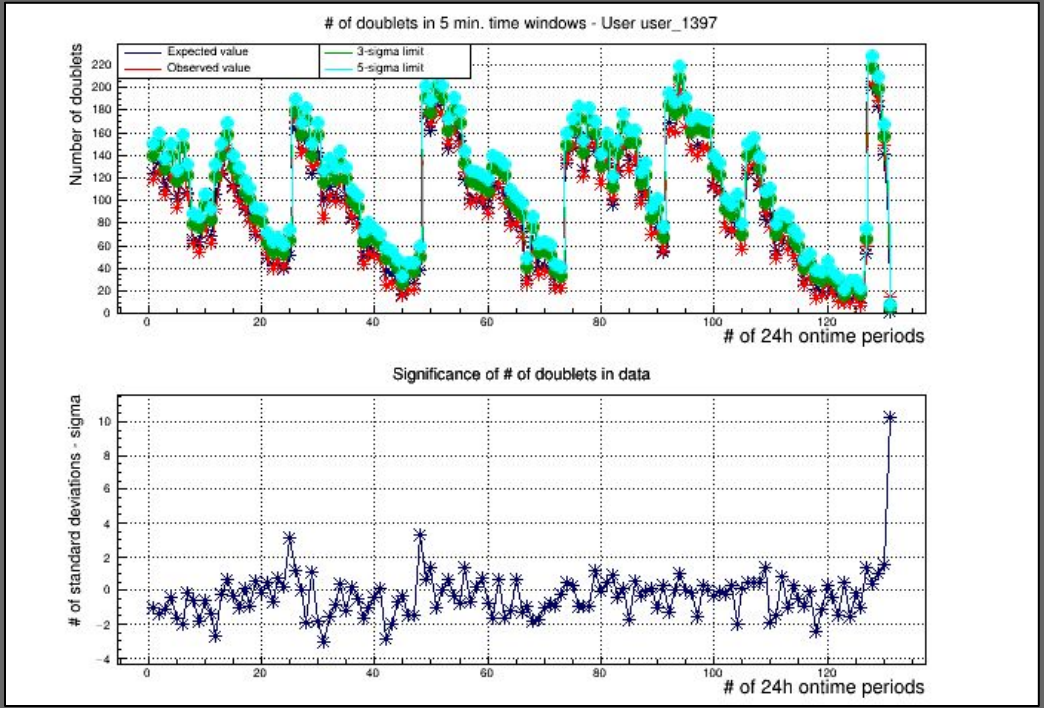
Extremely Distributed Observatory

Some results from the smartphone app...

Example of analysis on data from individual users



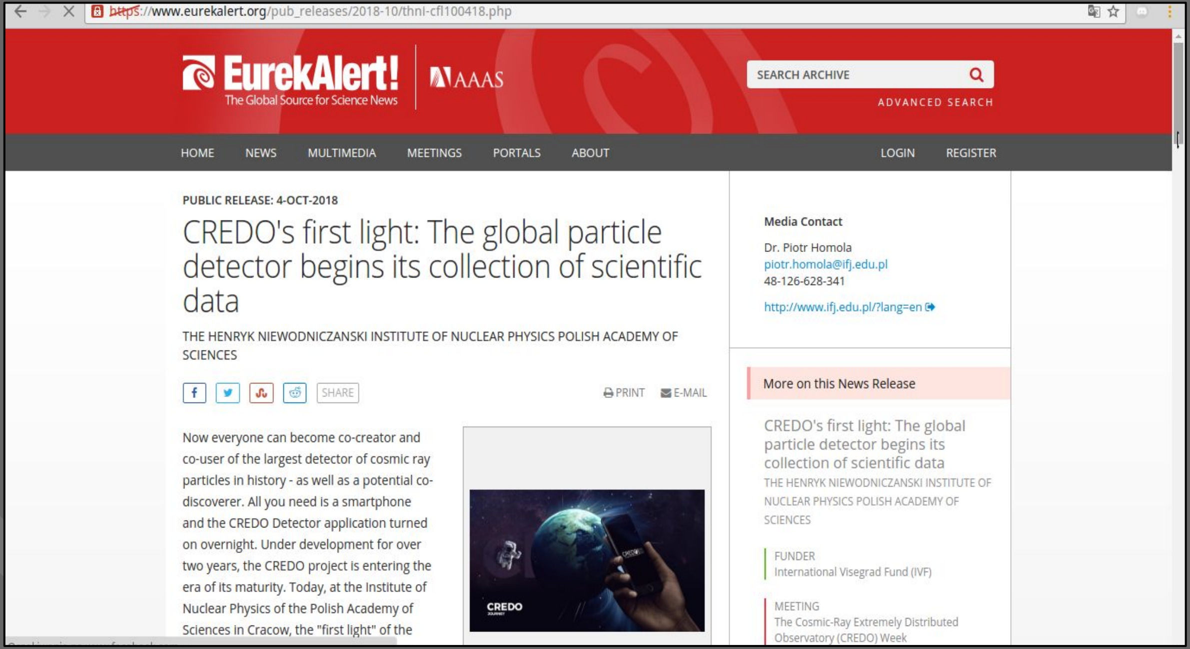
Active device in one week time period



★ **Day/night cycle** clearly visible!

Spreading the word…

<u>Citizen science</u> and <u>public outreach</u> constitute an key aspect of CREDO's strategy!



https://www.eurekalert.org/pub_releases/2018-10/thnl-cfl100418.php

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PUBLIC RELEASE: 4-OCT-2018

CREDO's first light: The global particle detector begins its collection of scientific data

THE HENRYK NIEWODNICZANSKI INSTITUTE OF NUCLEAR PHYSICS POLISH ACADEMY OF SCIENCES

SHARE PRINT E-MAIL

Now everyone can become co-creator and co-user of the largest detector of cosmic ray particles in history - as well as a potential co-discoverer. All you need is a smartphone and the CREDO Detector application turned on overnight. Under development for over two years, the CREDO project is entering the era of its maturity. Today, at the Institute of Nuclear Physics of the Polish Academy of Sciences in Cracow, the "first light" of the

CREDO

Media Contact

Dr. Piotr Homola
piotr.homola@ifj.edu.pl
48-126-628-341

http://www.ifj.edu.pl/?lang=en

More on this News Release

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FUNDER
International Visegrad Fund (IVF)

MEETING
The Cosmic-Ray Extremely Distributed Observatory (CREDO) Week

Conclusion

- **CREDO**: a unifying, global cosmic-ray project: GeV – ZeV→ completing the closest accessible approach to GUT scale. **20 institutions** representing **11 countries** (USA, V4, Australia, Russia, Mexico, etc.) are institutional members.

- Many others ongoing projects:
  - Ultra-high energy photon propagation simulations with CRPropa (**poster** by O. Sushchov).
  - Simulations of smartphone detectors' response to air showers.
  - Calibration of smartphones for air showers and muons.
  - Search for correlations between cosmic-rays and earthquakes on a global scale.
  - "*Gamification*" for public outreach and development of low-price detectors.

- New articles in process and first PhD thesis on the way!

THANK YOU FOR YOUR ATTENTION!

CREDO the 2nd Anniversary Symposium
IFJ PAN, Kraków, 4 October 2018

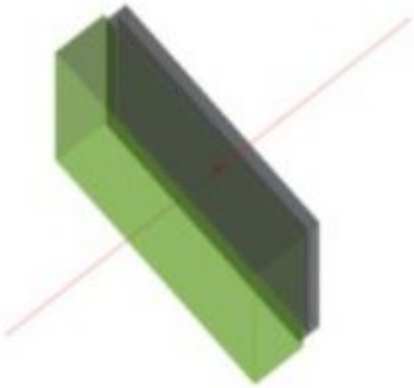
fot. Ireneusz Kochanek / FILMNET

Back-up

Smartphone camera sensor: Further Steps

Simulations of response of air shower particles with AllPix2.

- AllPix2: A generic, open source simulation framework for Si pixel detectors.
- Uses Geant4 for charge carrier deposition.
- Propagation of charge carriers in Si using a drift-diffusion model.

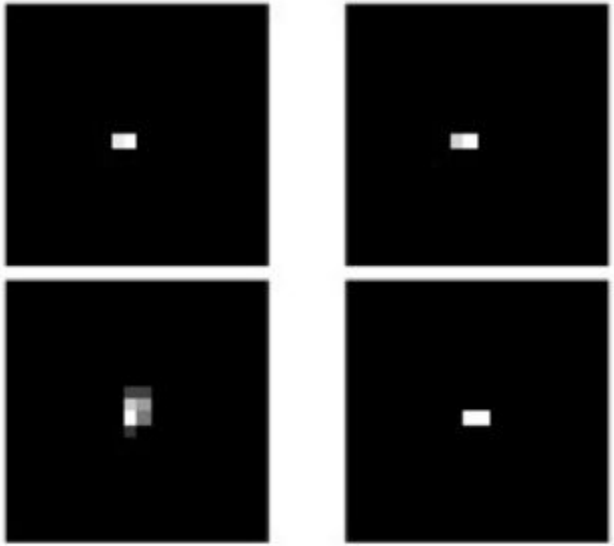


Simulation setup

Smartphone camera sensor: Further Steps

Simulations of response of air shower particles with AllPix2.

Some examples of simulated muon hits in smartphone detectors.

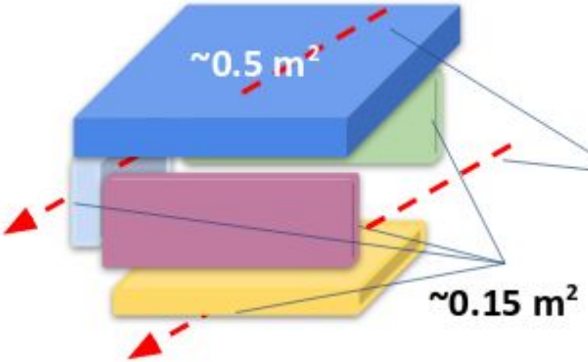


Simulation of response of cosmic ray particles to the camera sensors is feasible.

Smartphone detections: calibration for air showers and muons with scintillator plates

key work at IFJ PAN: Krzysztof Gorzkiewicz, Piotr Homola

ongoing / preliminary



Events registered simultaneously in at least **3 different detectors**

= air showers (N_{muon}>1)

observed ~15000 / day

(cf. c.a. 10000 10^{12} eV air showers expected per m² per day, verifying with simulations in progress - N. Dhital)

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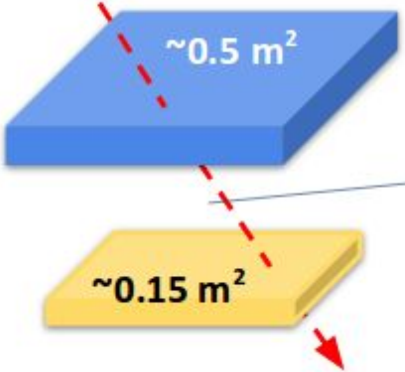


Events registered simultaneously in the top and bottom detectors = air shower muons

observed ~400,000 / day

(compatible with background vertical muons expected per 0.15 m^2 per day, data analysis in progress - N. Dhital, P. Homola)

In the literature...

VOLUME 50, NUMBER 26 PHYSICAL REVIEW LETTERS 27 JUNE 1983

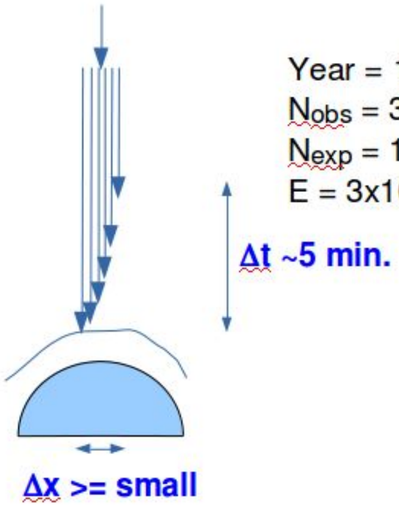
Possible Observation of a Burst of Cosmic-Ray Events in the Form of Extensive Air Showers

Gary R. Smith, M. Ogmen, E. Buller, and S. Standil
Physics Department, University of Manitoba, Winnipeg, Manitoba R3T 2N2, Canada

(Received 7 April 1983)

A series or burst of 32 extensive air showers of estimated mean energy 3×10^{15} eV was observed within a 5-min time interval beginning at 9:55 A.M. (CST) on 20 January 1981 in Winnipeg, Canada. This observation was the only one of its kind during an experiment which recorded 150 000 such showers in a period of 18 months between October 1980 and April 1982.

PACS numbers: 94.40.Pa, 94.40.Rc, 95.30.-k



Year = 1981
N_{obs} = 32
N_{exp} = 1
E = $3\text{x}10^{15}$eV