Cosmic Ray Extremely Distributed Observatory: Status and Perspectives of a Global Cosmic Ray Detection Framework

Dariusz Góra[1], Kevin Almeida Cheminant[1], Niraj Dhital[1], Piotr Homola[1], Oleksandr Sushchov[1], Dimitriy Beznosko[2], Jilberto Zamora-Saa[3]
for the CREDO Collaboration*

[1)] *Institute of Nucler Physics PAS, Cracow;*
[2)] *Bard College, New Orleans, USA;*
[3)] *Universidad Andres Bello, Departamento de Ciencias Fisicas, Facultad de Ciencias Exactas, Avenida Republica 498, Santiago, Chile*

* http//credo.science

Outline :

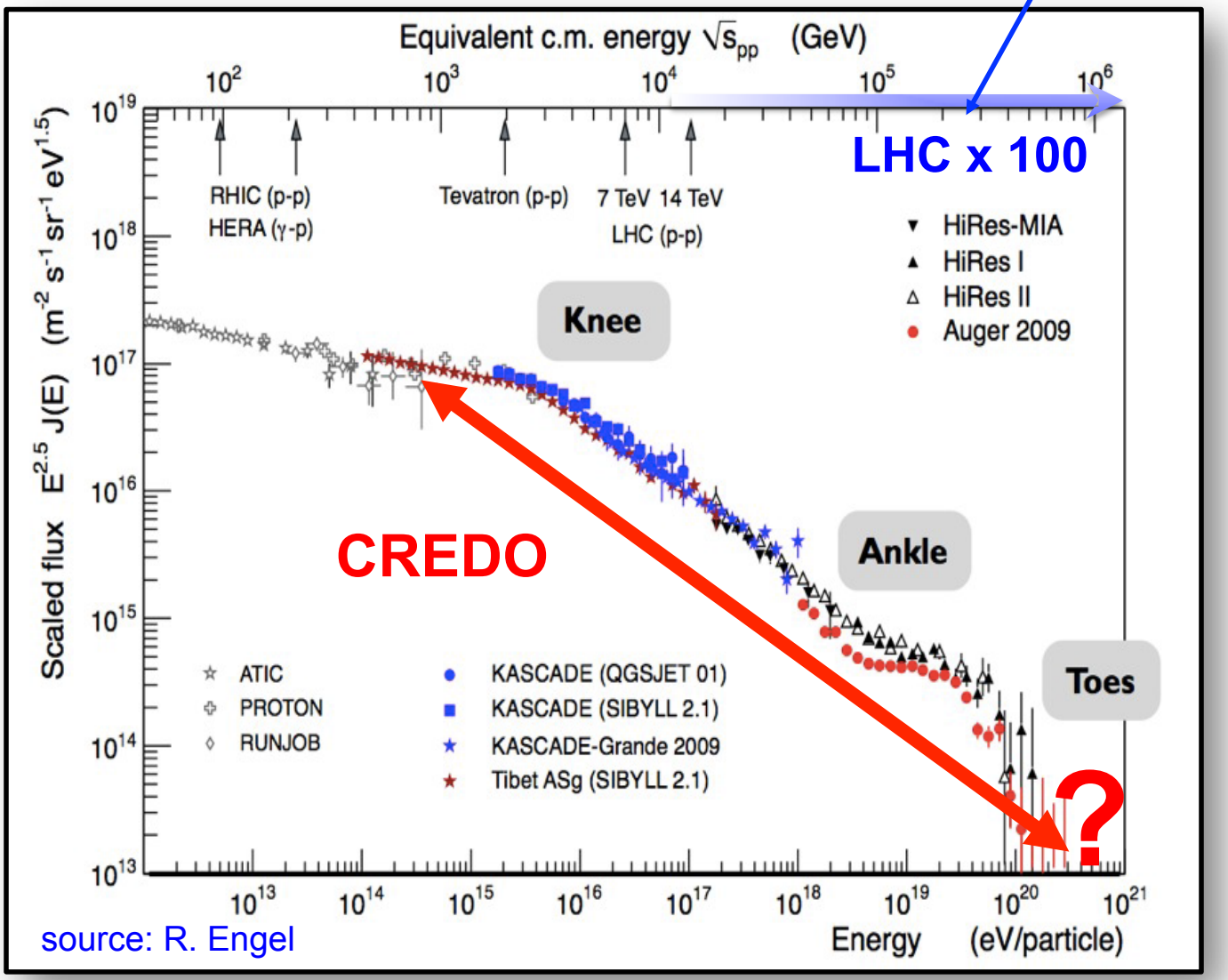
- Introduction: Cosmic rays, preshower effect
- Mobile aplication and the first results
- Citizien science
- Summary

PoS(ICRC2019)272

36th International Cosmic Ray Conference, July 24th - August 1st, 2019, Madison, WI, U.S.A.

The Ultra-High-Energy Cosmic Ray mystery

Particle physics beyond the reach of colliders



source: R. Engel

> What's their composition?

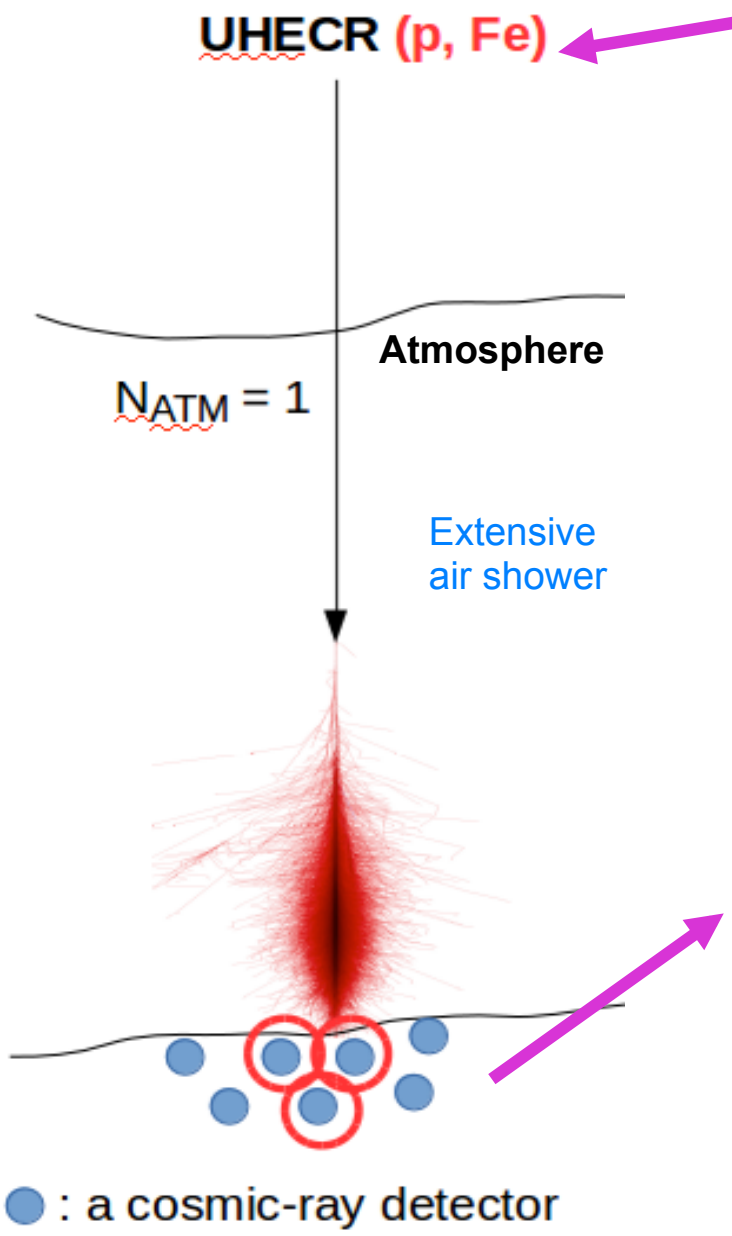
> Where do they come from?

→ *anisotropies weakly correlated to known possible sources: active galactic nuclei, gamma-ray burst,…*

> How do they reach such tremendous energies?

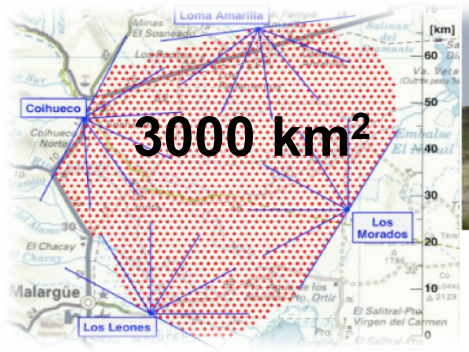
Spectrum suppression:
in the past: *the GZK cut-off*
now: *rather the efficiency limit of particle acceleration by sources*

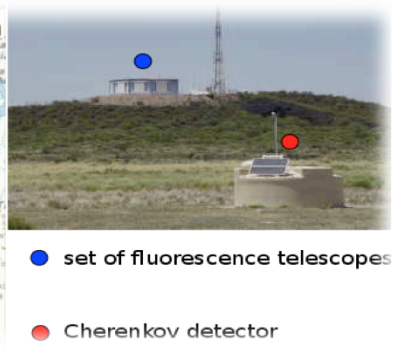
Motivation: typical strategy

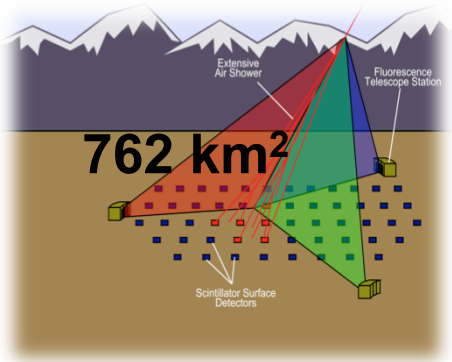


*A **single particle** hits the atmosphere and produces a **single air shower** that can be reconstructed by detectors on the ground via various channels of observation, such as Cherenkov radiation or fluorescence light.*

Typical strategy: **looking for ONE shower**
i.e. *Pierre Auger Observatory, Telescope Array, IceTop ....*



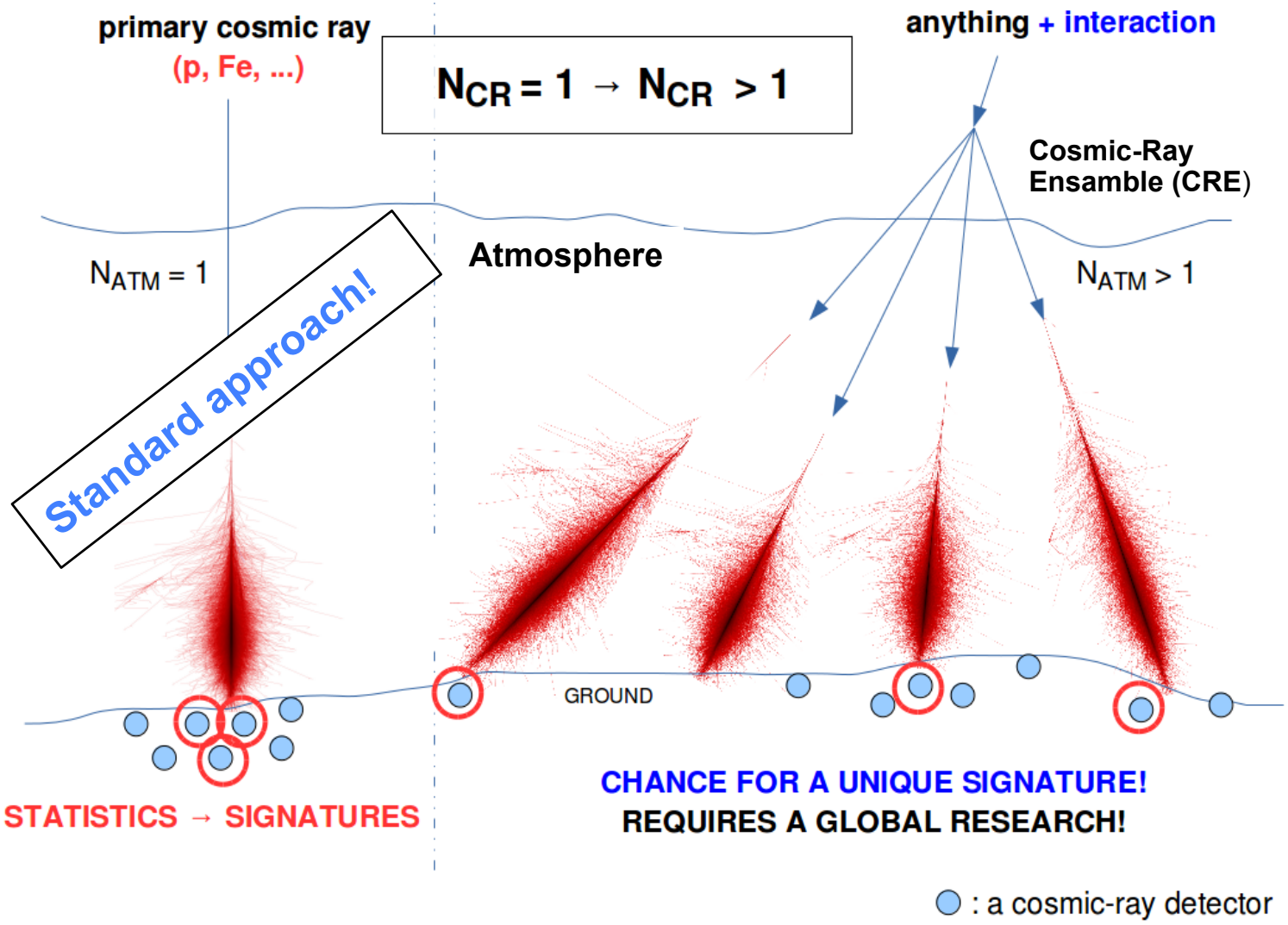




...

Motivation: looking for Cosmic Ray Ensambles (CRE)

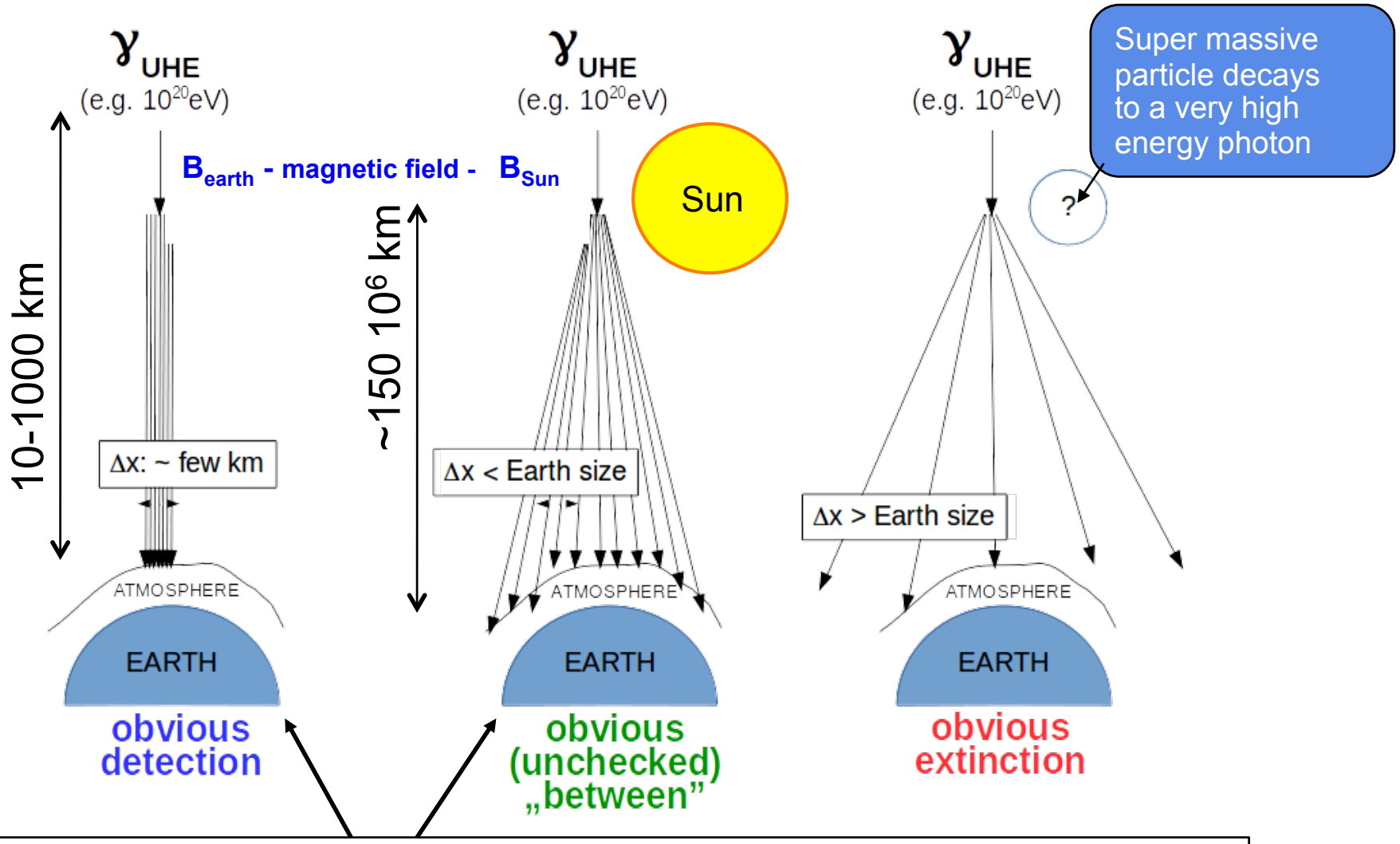
... many air showers and individual particles arriving simultaneously to the Earth ($N_{CR} > 1$)



CREDO strategy: Looking for multiple air showers correlated in time

Classes of CRE

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



$N_{cr} > 1$ scenario have been reported in the literature:

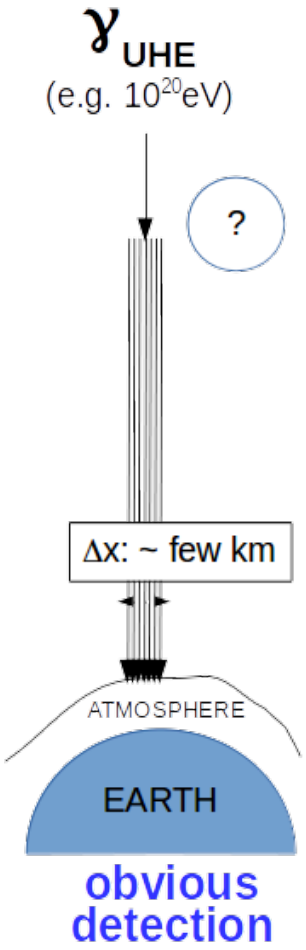
G.R. Smith et al., Phys. Rev. Lett. 50 (1983) 2110;177; D.J. Fegan and B. McBreen, Phys. Rev. Lett. 51 (1983) 2341

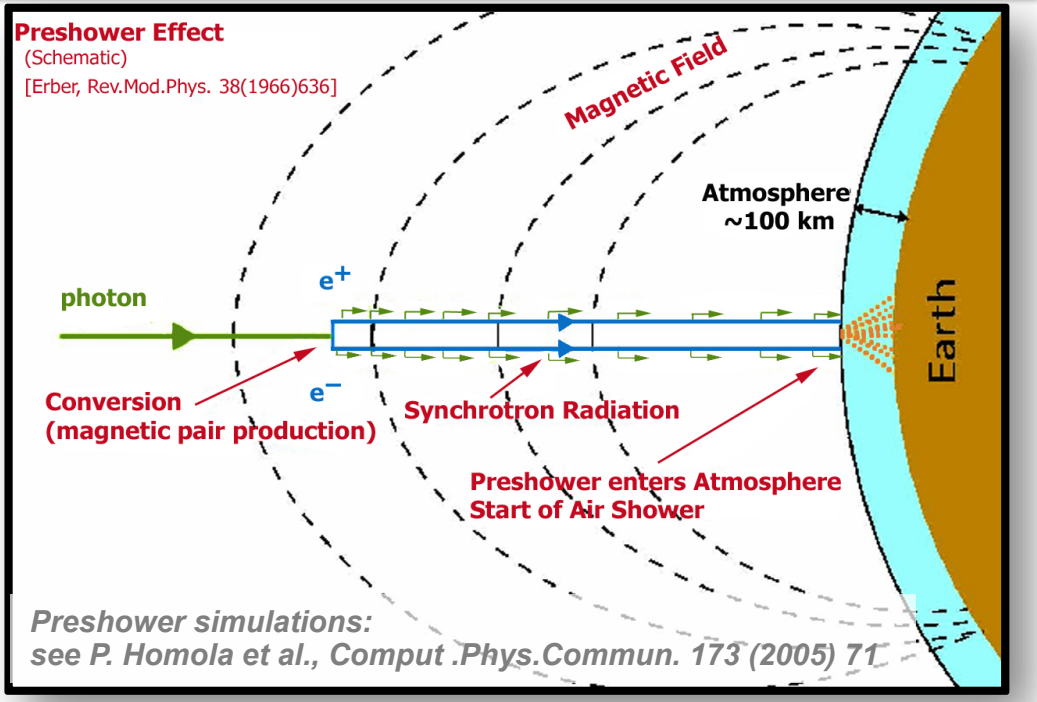
but they have not been observed repeatedly until now.

Example of CRE : Preshower near the Earth

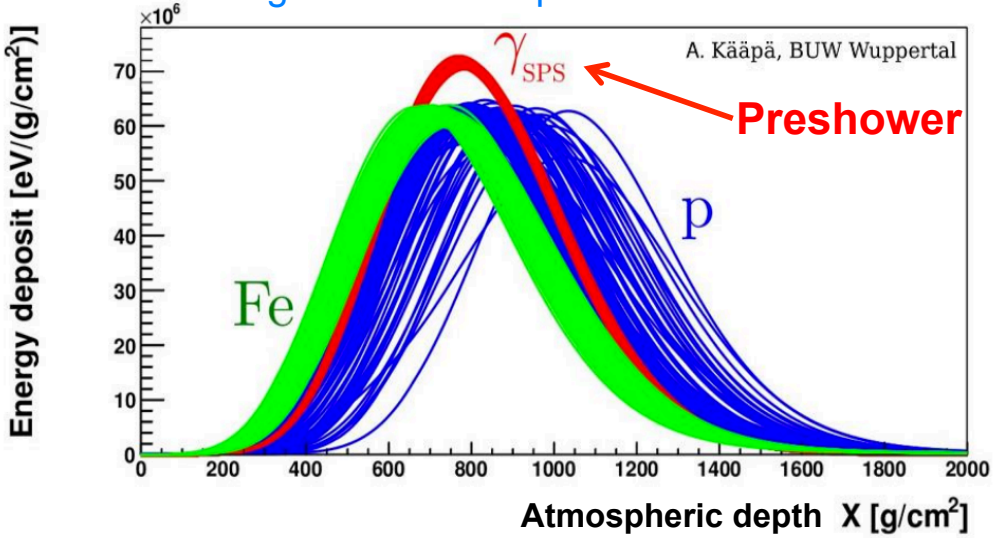
Preshower: cascade of electromagnetic particles

Typical altitude 1000 km a.s.l.,
N_{part} at the top of the Earth's atmosphere ~100





Preshower could be difficult to detect by fluorescence cosmic ray detectors, because it's longitudinal development of air shower looks similar to the hadronic one

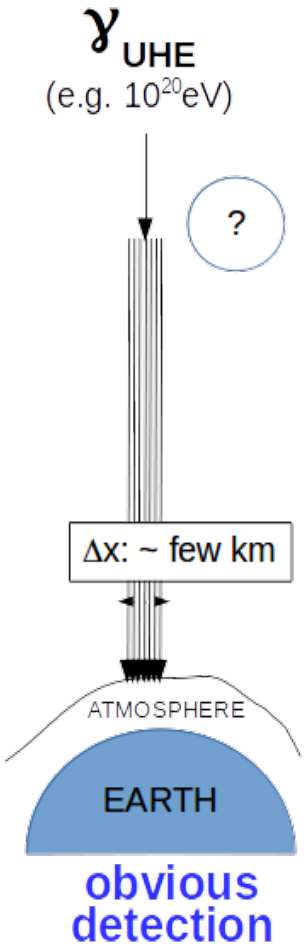


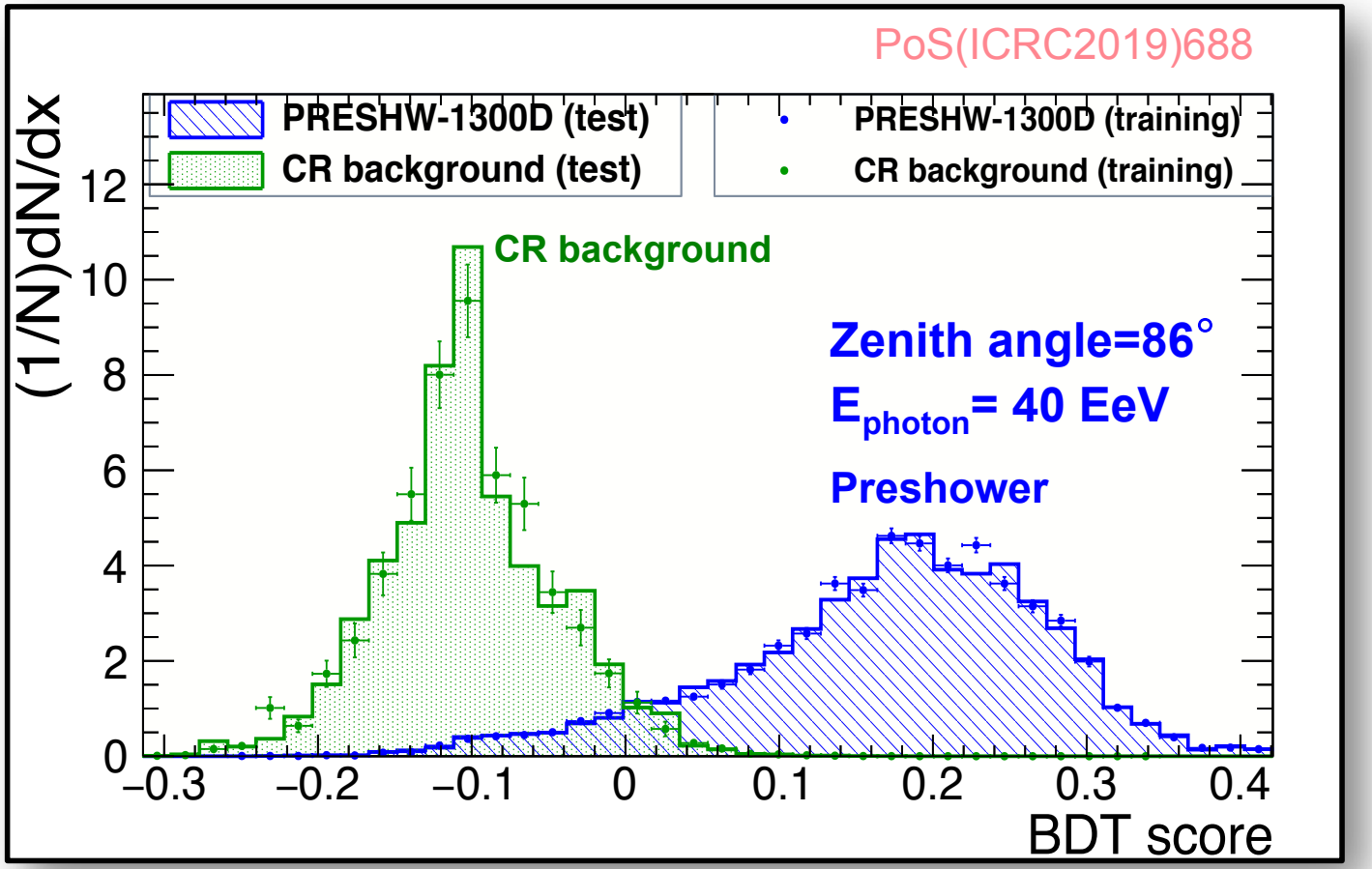
Example of CRE : Preshower near the Earth

> Preshower effect as an **indirect proof of UHE photons existence**

Nearly-horizontal observation mode for gamma-ray telescopes located at La Palma site

Allows to retrieve **gamma/hadron separation** and search for preshower by Imaging Atmospheric Cherenkov Telescopes (IACTs), non-standard approach!

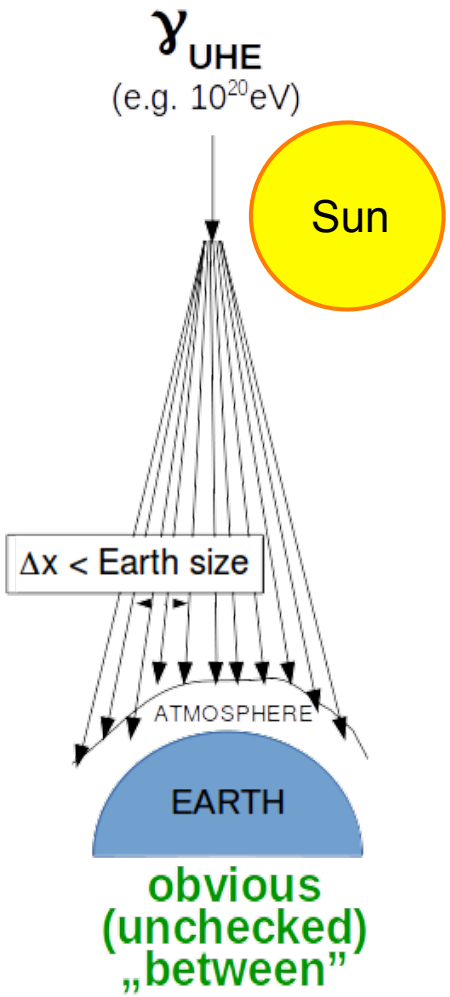


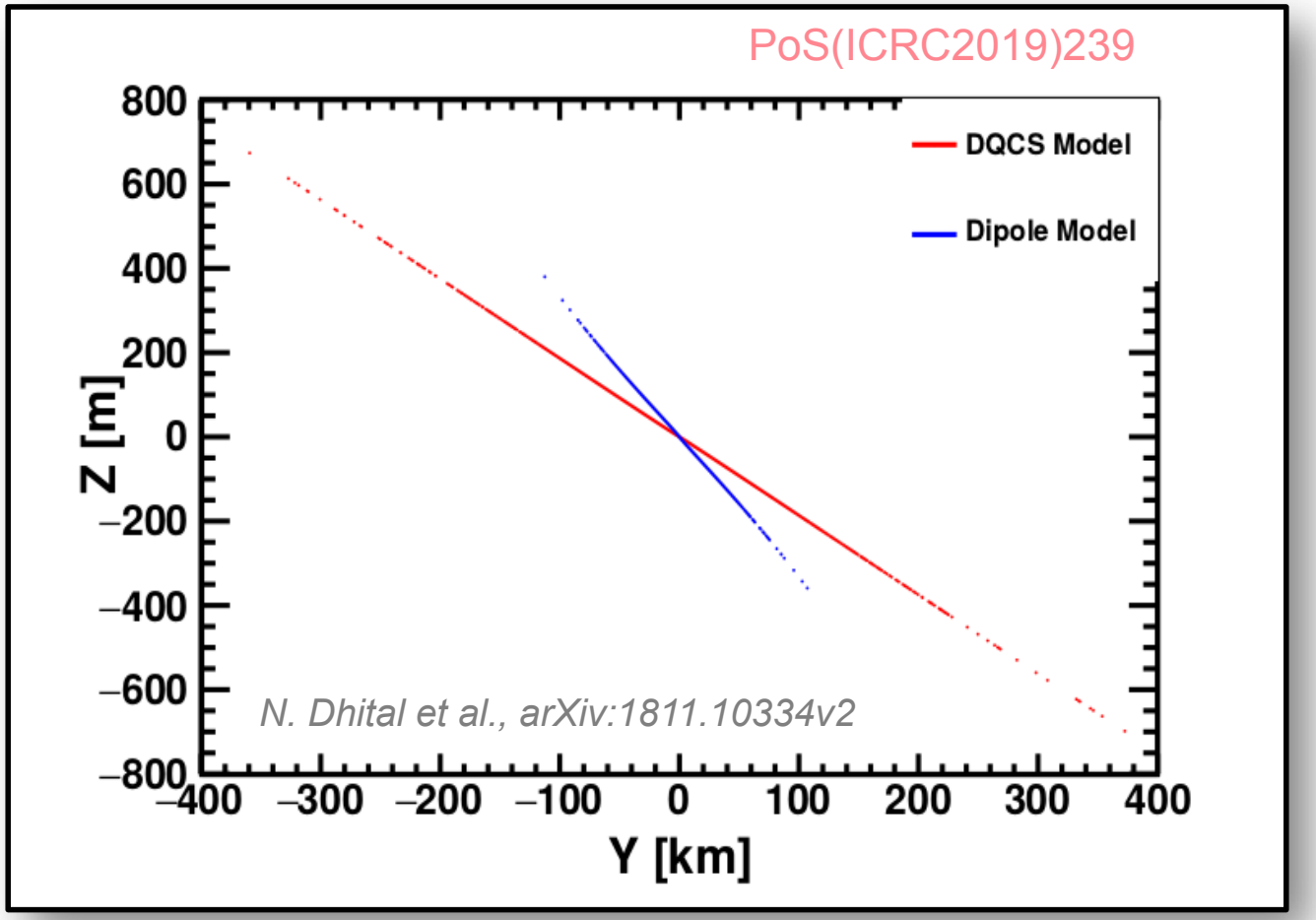


Example of CRE : Preshower near the Sun

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

> New simulations: all energy spectrum → extent ~ **thousands of km** at the top of the atmosphere.





Typical particle distribution at the top of atmosphere for 100 EeV photon interacting close to the Sun (3 $R_\odot$)

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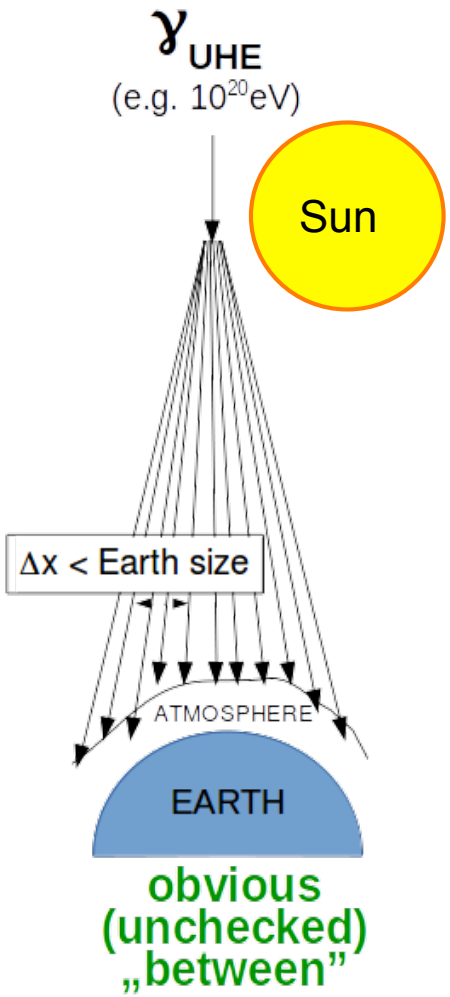

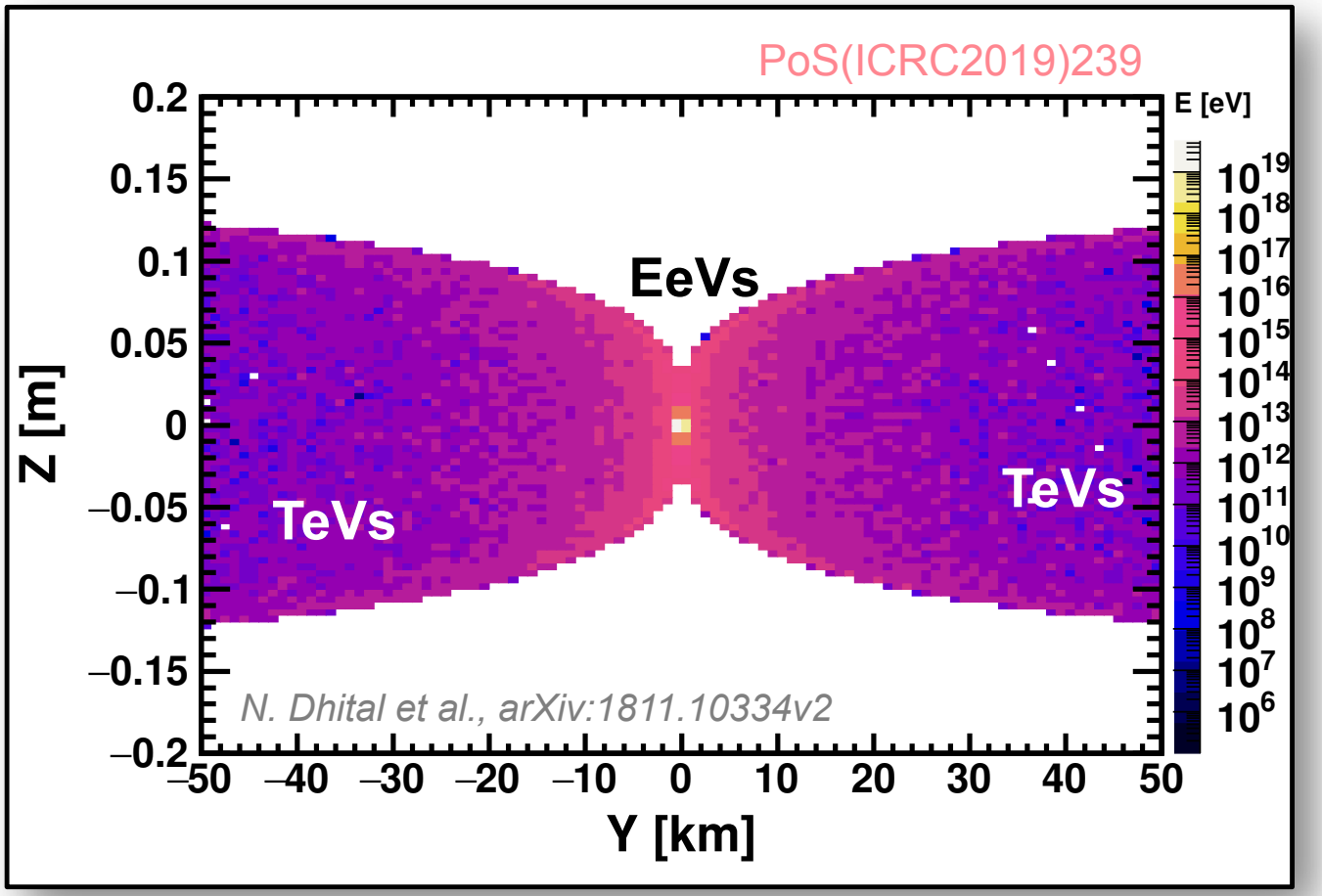

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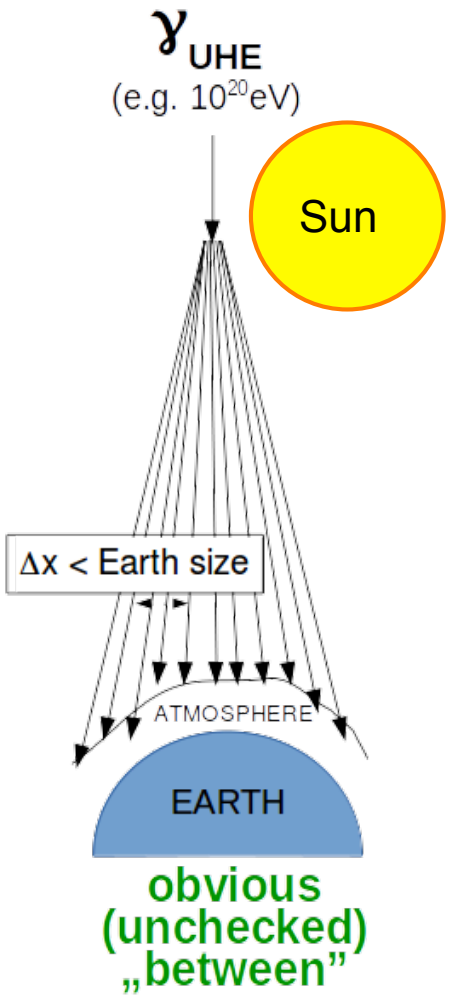
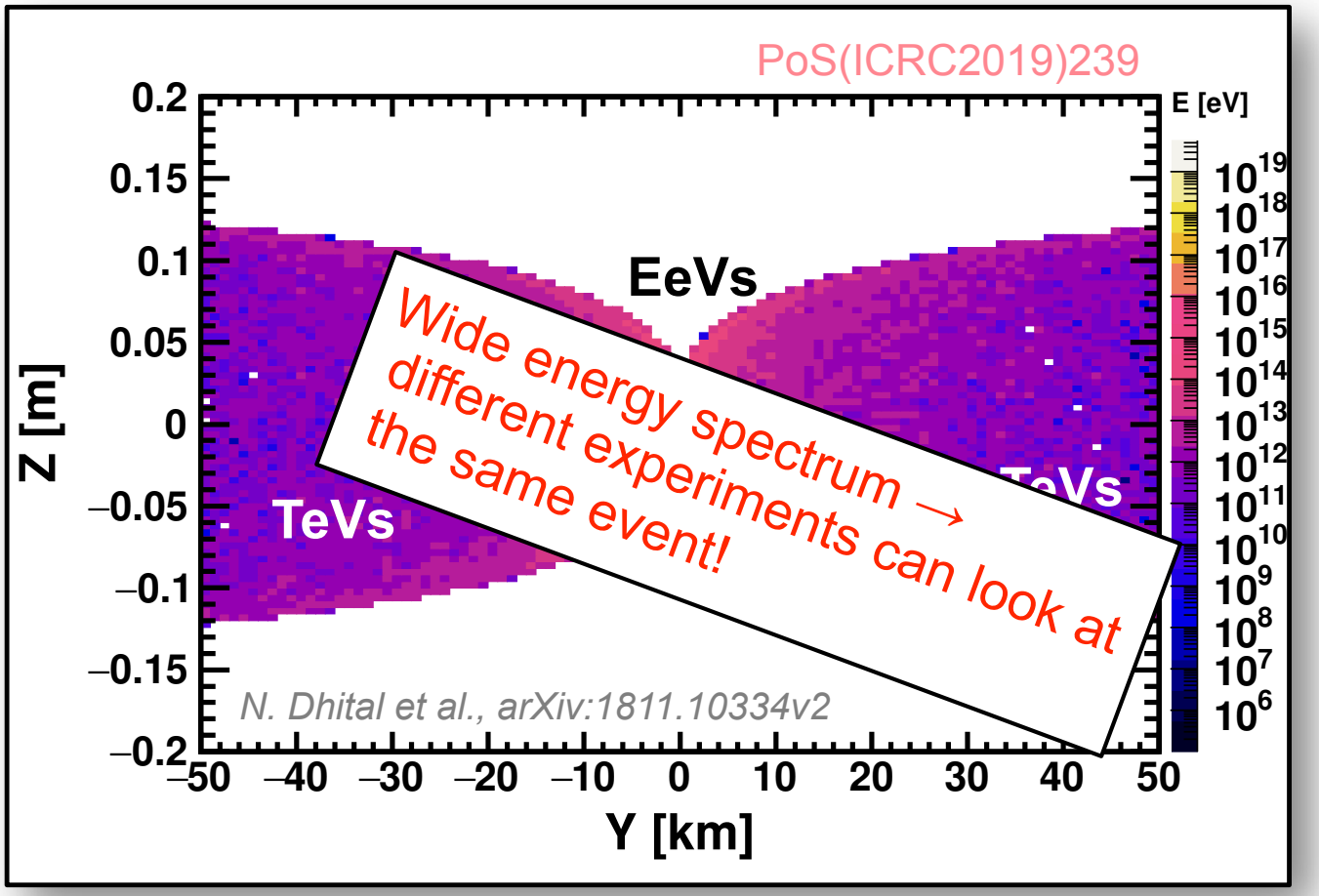


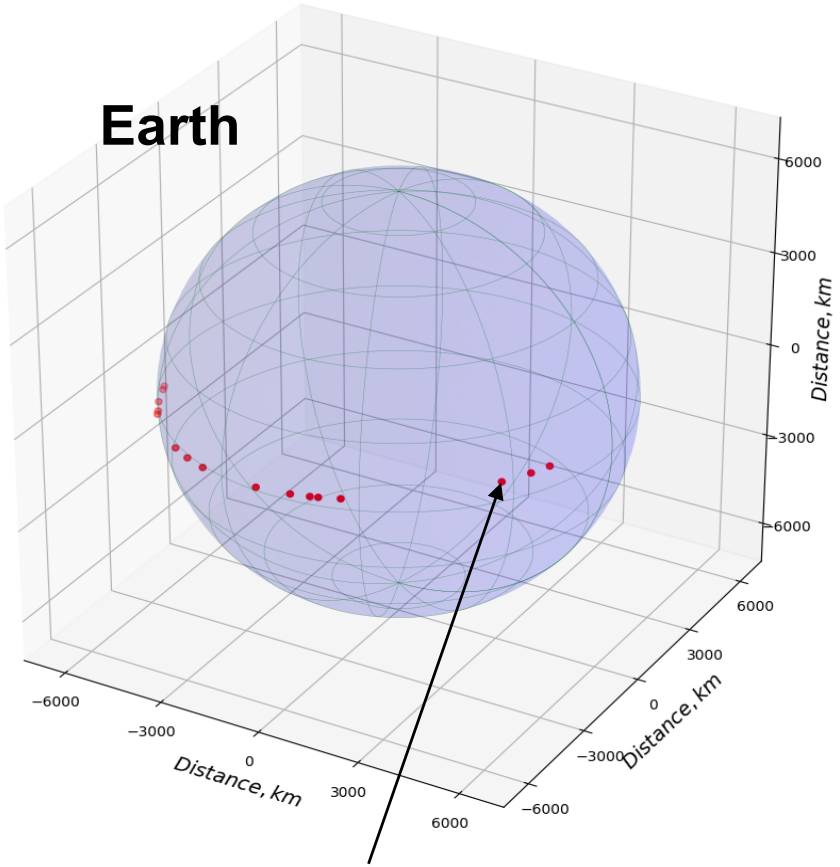


Typical particle/energy distribution at the top of atmosphere for 100 EeV photon interacting close to the Sun (3 $R_\odot$)

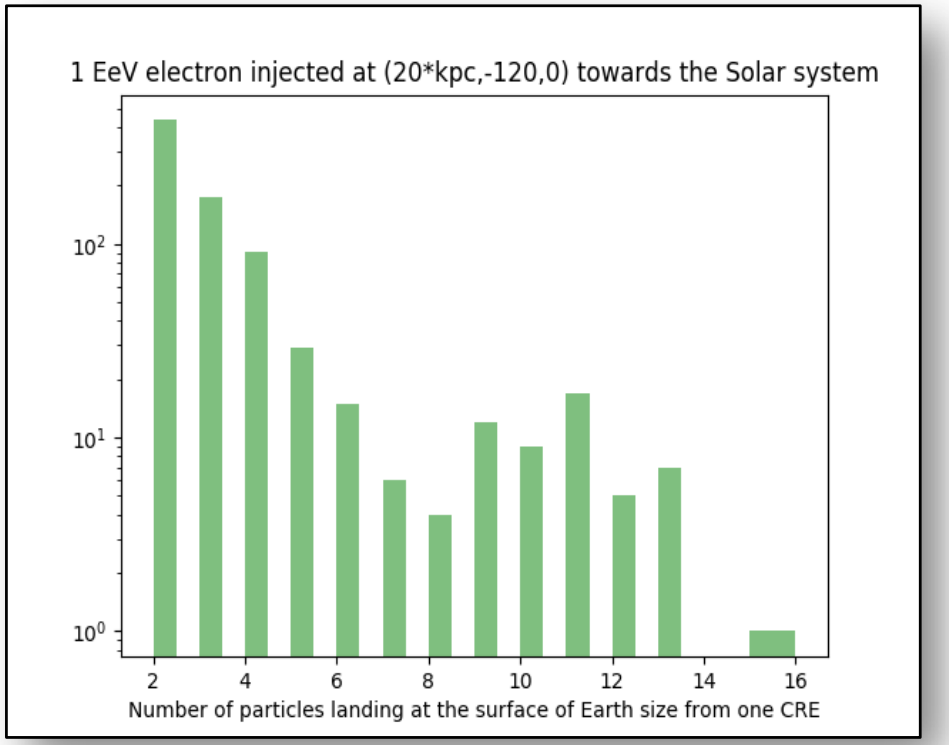
Example of CRE : Electron entering our Galaxy

>1 EeV electron entering the galaxy, and heading towards the Solar system, PoS(ICRC2019)239

CRPopa 3 simulations considering the galactic magnetic field (GMF) of Jansson&Farrar (JF12) model



Positions of CRE photons arriving at the Earth



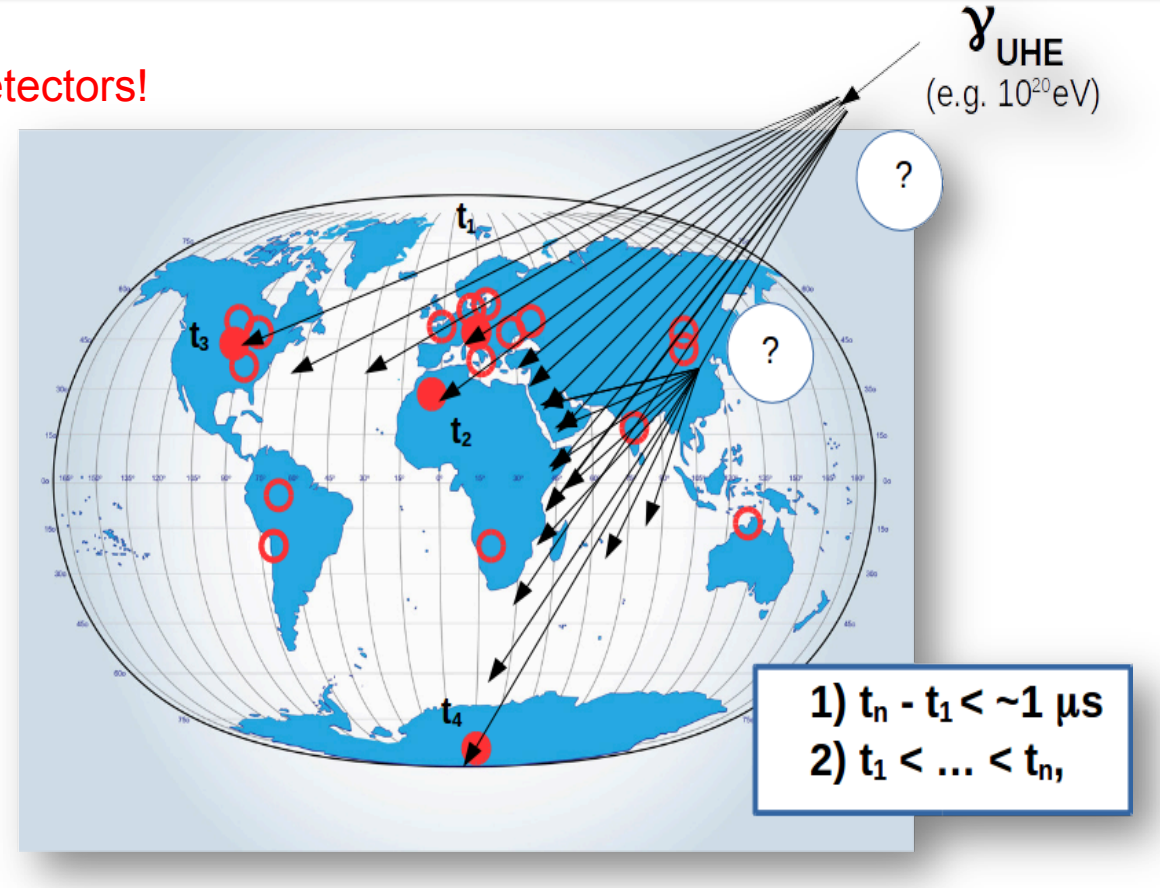
Distribution of number of photons with energies > 1 TeV landing at the Earth.

Cosmic-ray Extremaly Distributed Observatory

CREDO's main idea:

creating a global network of particle detectors!

How?...



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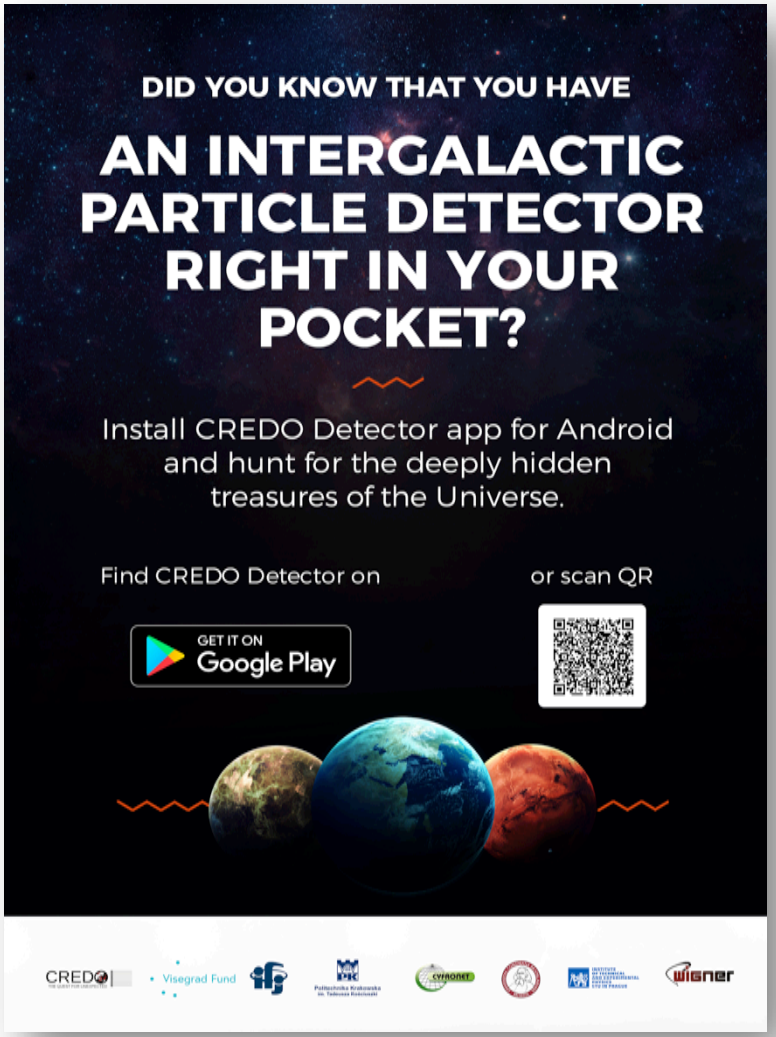

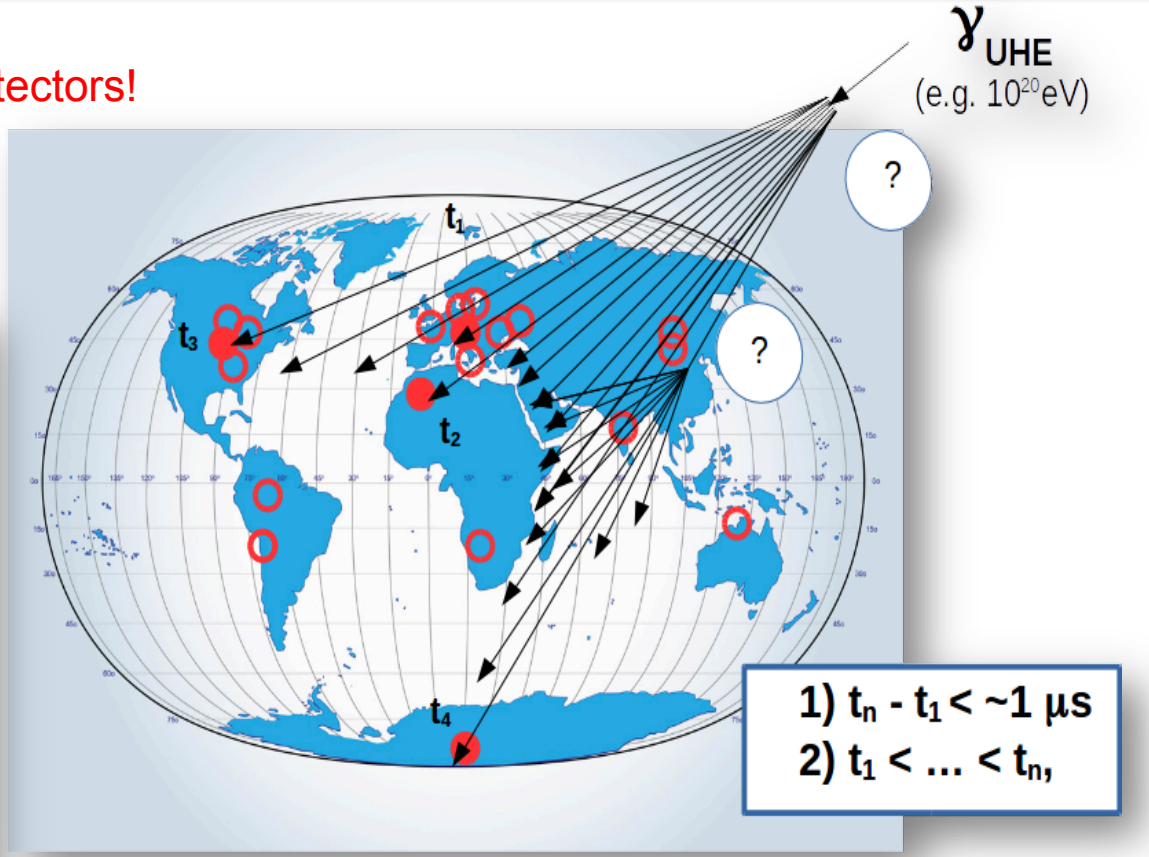

Code of application is public on GitHub:
https://github.com/credo-science
Different version available:
CREDO-PC-Windows, CREDO-Desktop-Det., Raspberry-Pi,...

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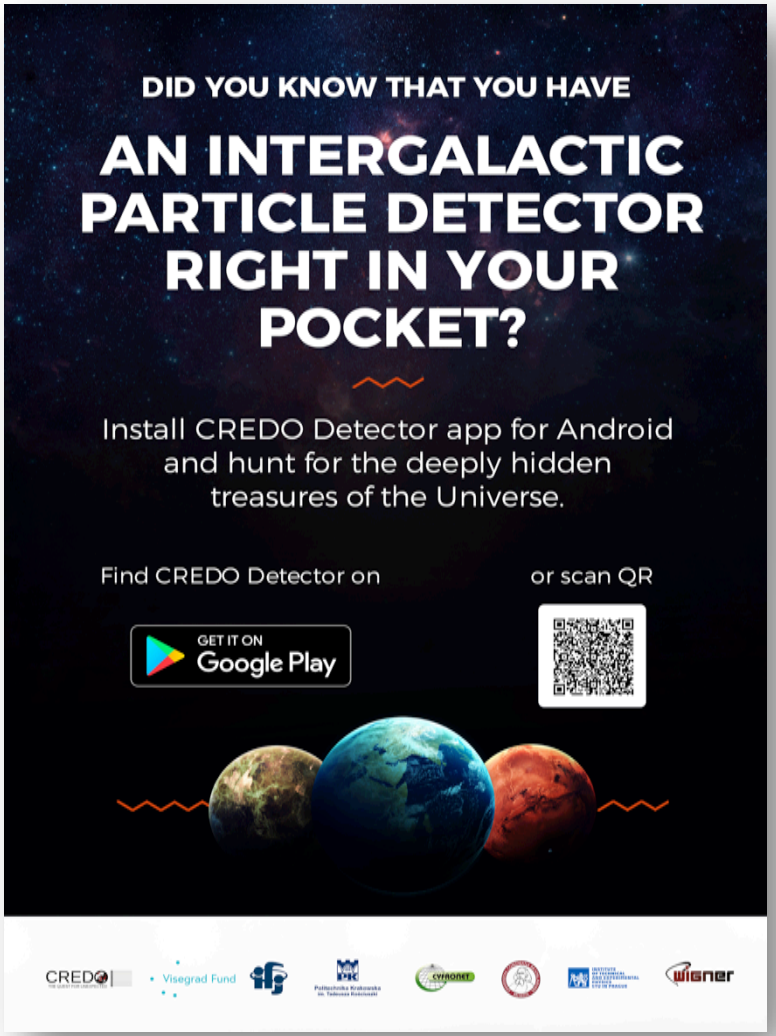

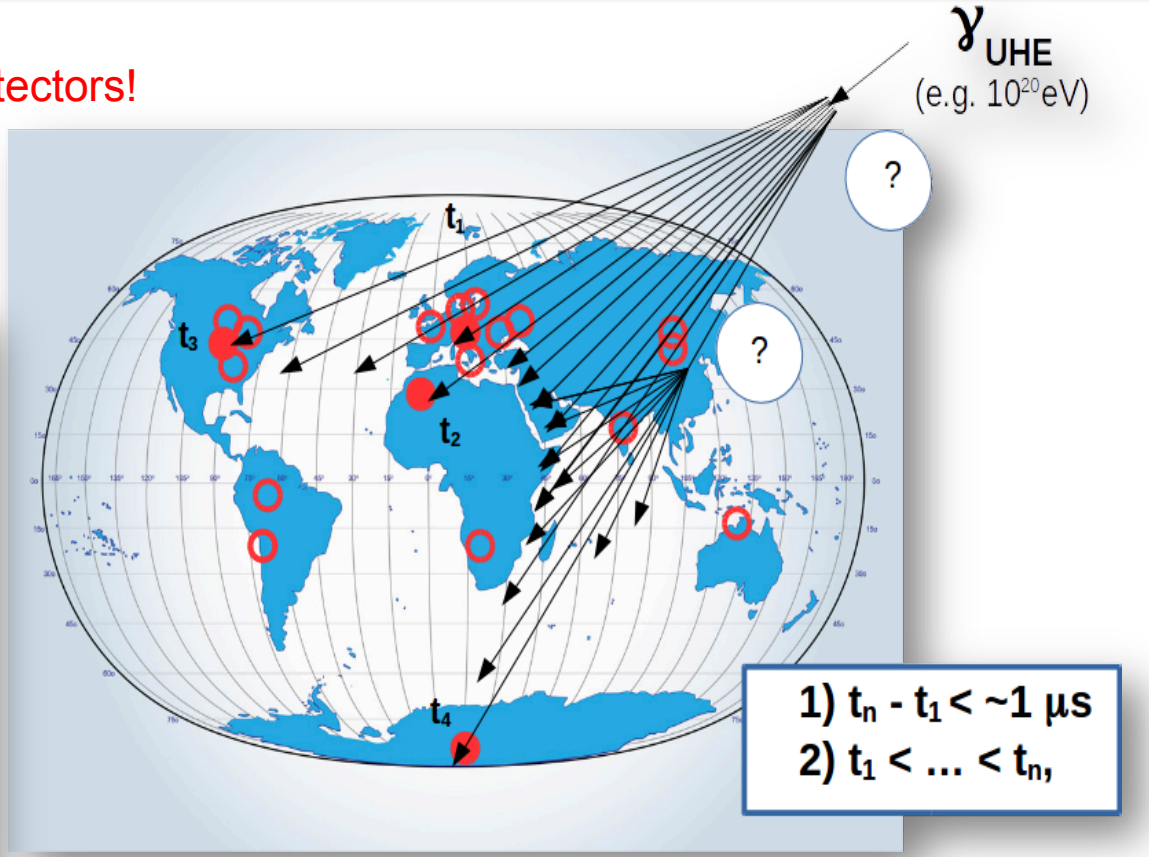

+ small type of scintilator detectors, PoS(ICRC2019)428
+ connecting **existing observatories** to the network

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Mobile application

> Smartphone application developed by CREDO collaboration, PoS(ICRC2019)367

Motivation: D. Groom, *Cosmic rays and other nonsense in astronomical CCD imagers*, Experimental Astronomy (2002) 14, 45

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.

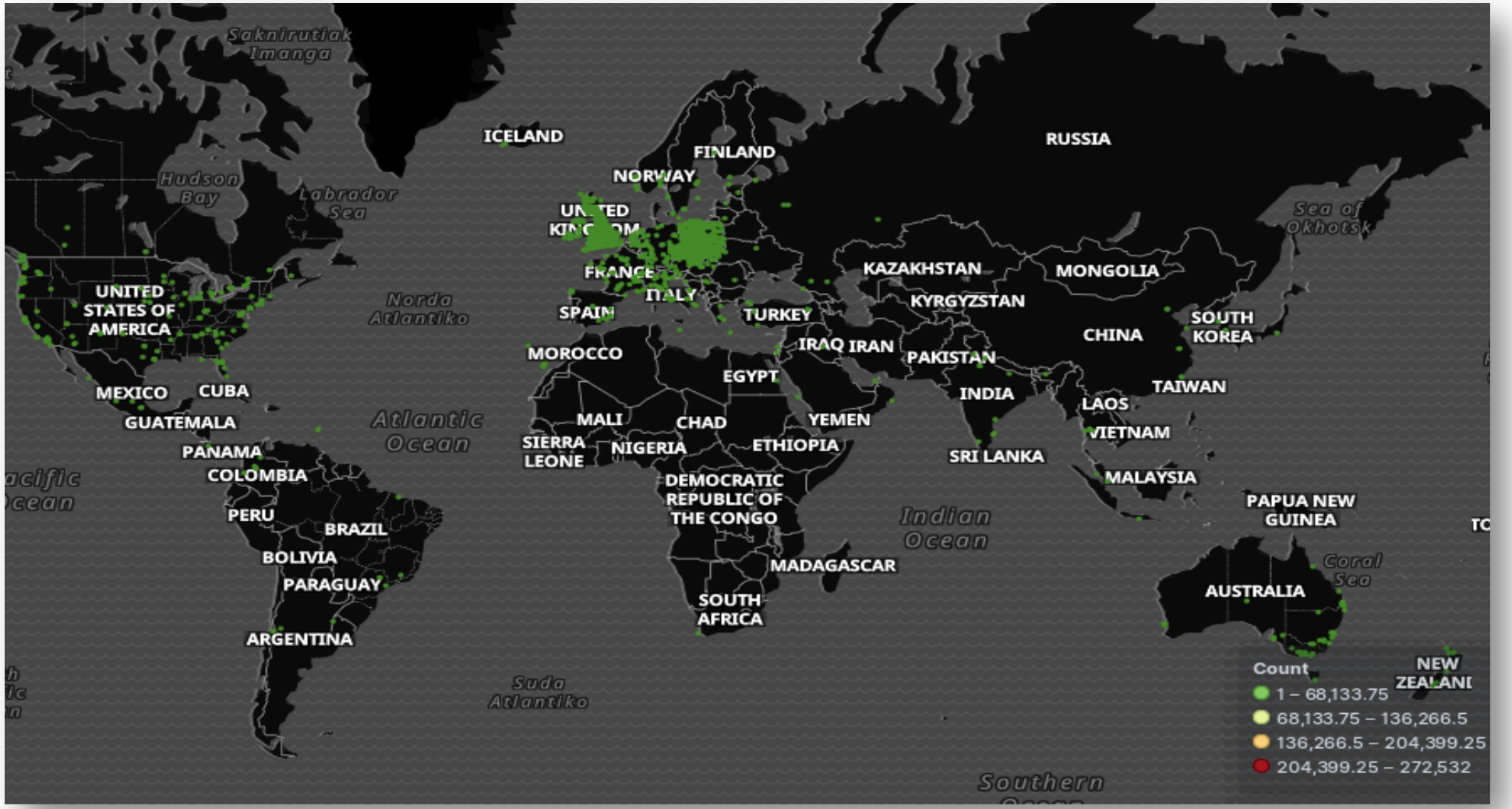
> Users can access the data they collected and see the results from the analysis run on their data

STIMULATES CITIZEN SCIENCE !

**The DECO/CRAFIS project* demonstrate discrimination between GeV cosmic-ray muon tracks and MeV electron, see Journal of Instrumentation 2016 11, P04019; M. Winter et al., Particle Identification In Camera Image Sensors Using Computer Vision, Astropart. Phys. (2019), 104, 92. However, large number of smartphones (~10^6 M. Unger and G. Farrar, [arXiv:1505.04777] are needed to reach the sensitivity comparable to the largest cosmic-rays observatories.)

Mobile application: we already reach the global scale !

> Location of users since the launch based on data from: *https://api.credo.science/web/*

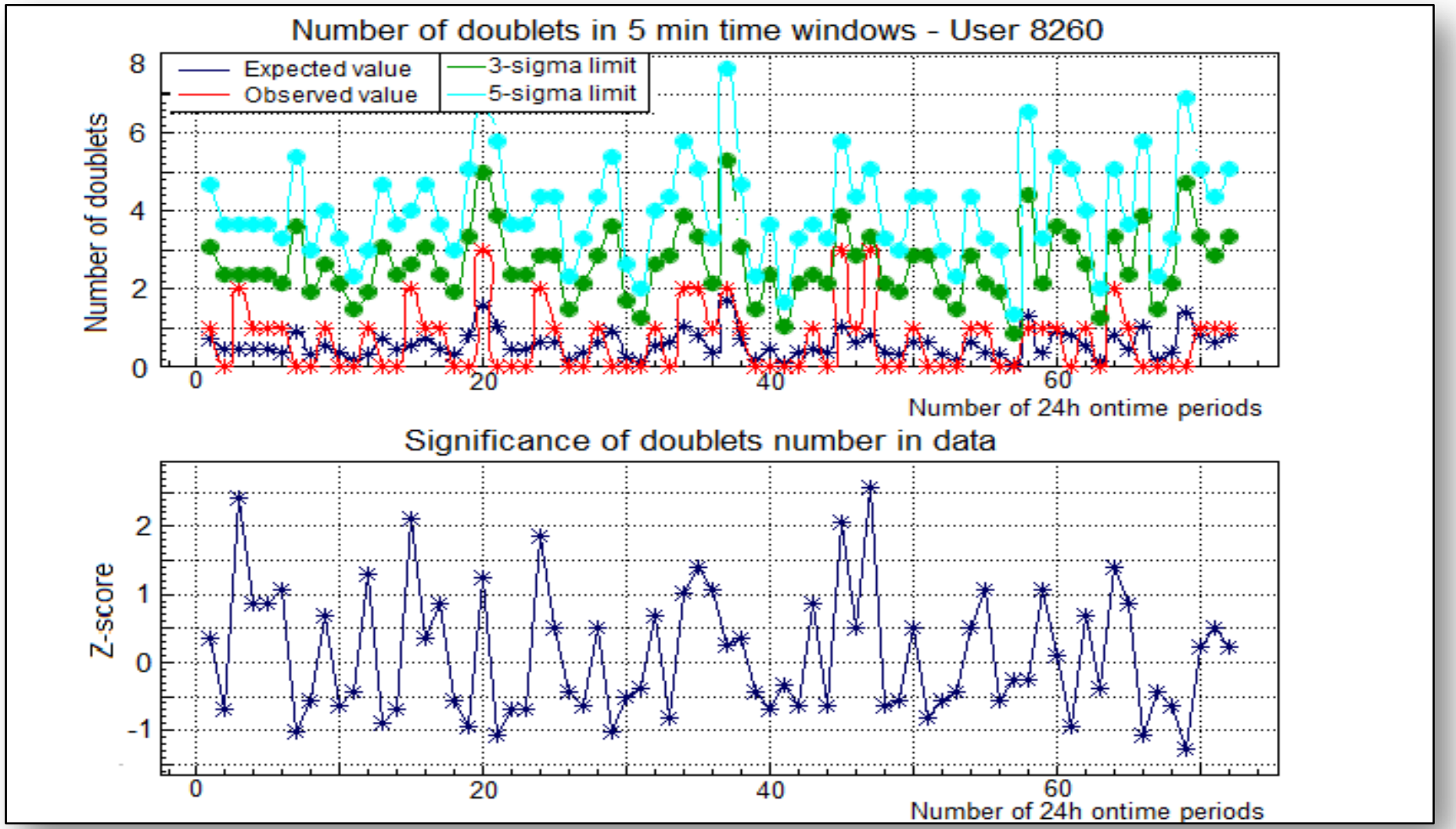


Statistics from launch to July 25th 2019: > **7500 users** with at least 1 detections

~3 200 000 detections App running time sums up to **947 years**

Example of analysis on data from individual users

> **First achievement (4.10.2018):** the signal from the first automatized, mass participation scientific experiment on the CREDO infrastructure



A significance of given doublet is calculated using scrambled technique, as described in *D.G. et al., Universe, 4(11) (2018) 111*.

IT resources

Mainframe (AGH Univ., Krakow)

Visegrad Fund

CYFRONET

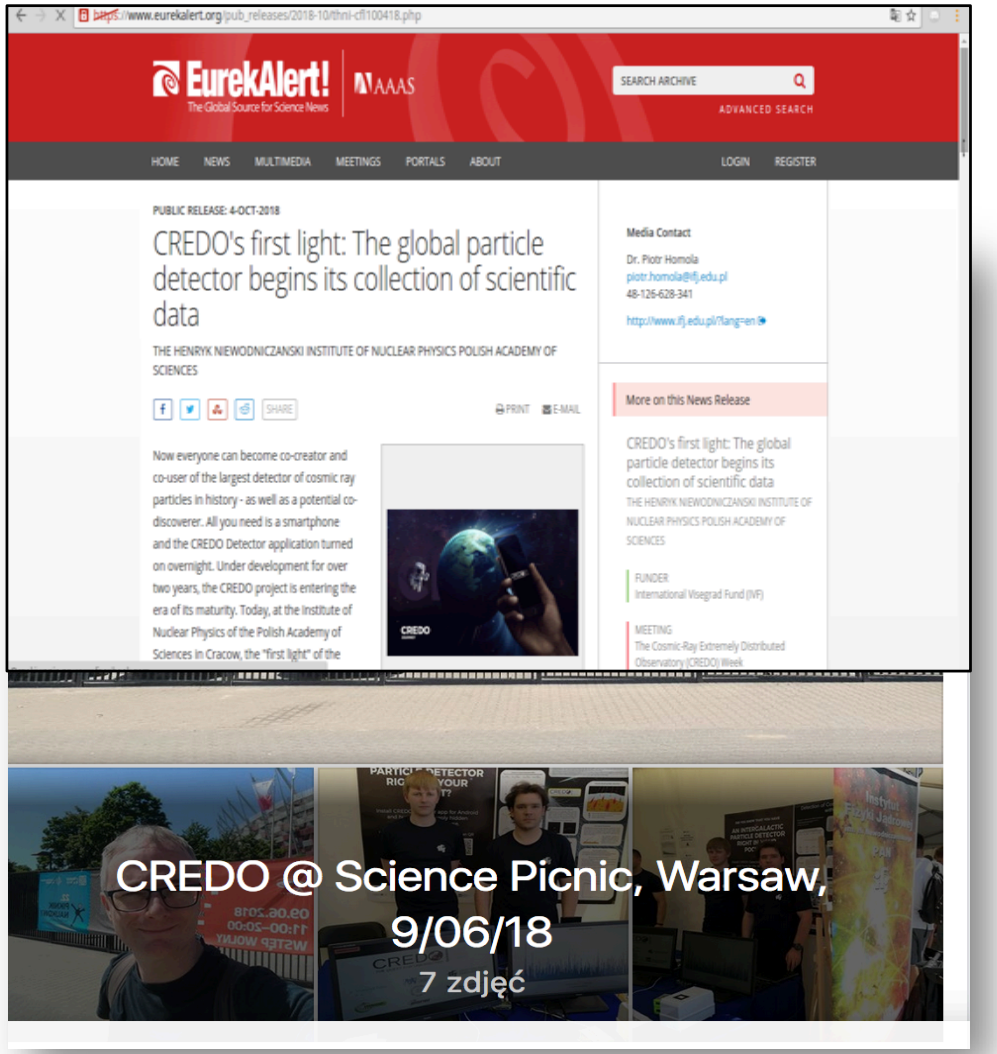
2140 TFLOPS in CPUs + 256 TFLOPS in GPUs
2232 nodes, 53568 CPU cores, 279 TB RAM
10 PB usable disk space @ 180 GB/s

The CREDO heart :)

2.4 PFLOPS, #59 ON TOP500

Spreading the word...

> The second goal of CREDO involves a large number of participants (citizen science!)



Particle Hunters League and Marathon!
Not only for schools!

https://credo.science/lowcyczastek

> Conferences: CREDO week,…
https://indico.ifj.edu.pl/event/213/

July 2019: ~ 1200 participants
from ~ 60 schools!

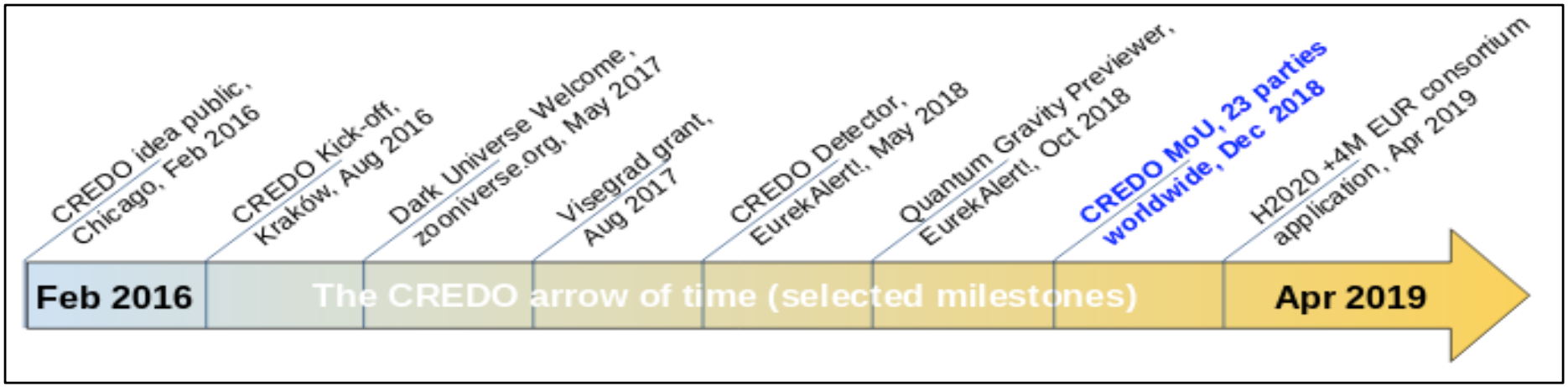
Conclusion

CREDO: a unifying, global cosmic-ray project: GeV – ZeV→ completing the closest accessible approach to GUT scale.

23 institutions representing **11 countries** (Australia (2),Czech Republic (2) Georgia (1), Hungary (1), Mexico (1), Nepal (1), Poland (8), Russia (1), Slovakia (1), Ukraine (2), USA (3)) are institutional members.

Many others ongoing projects:

- Ultra-high energy photon propagation simulations with CRPropa.
- 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



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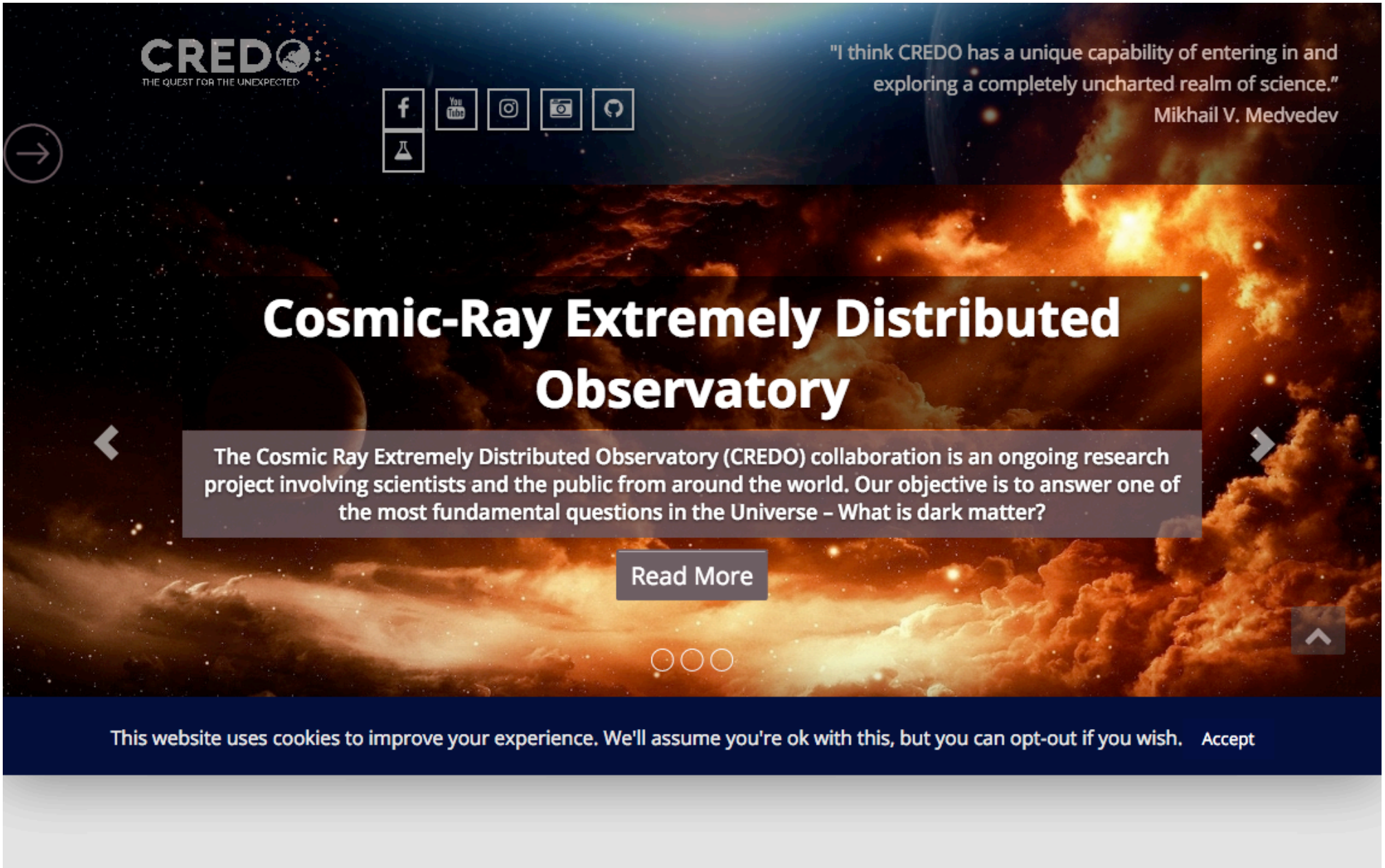
...and visit us on http://credo.science



CRE: 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)

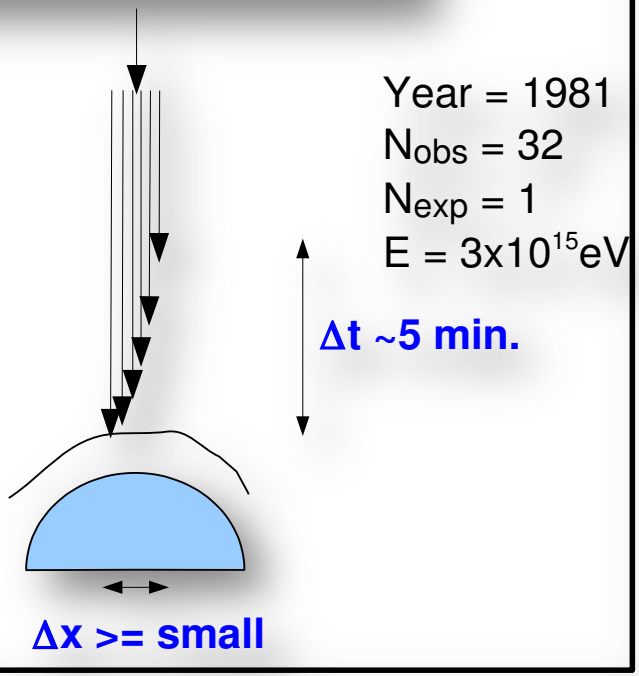
A series or burst of 32 extensive air showers of estimated ... energy 3×10^{15} eV was observed within a 5-min time interval beginning at 9:55 A.M. (CST) on 20 January 1981 in Winnipeg, Canada. This observation was the only one of its kind during an experiment which recorded 150 000 such showers in a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

PACS numbers: 94.40.Pa, 96.Rc, 95.30.-k

Forgotten (!) treasure (?) no. 1

Correlated cosmic rays?

$N_{ATM} > 1$?



CRE: in the literature

VOLUME 51, NUMBER 25 PHYSICAL REVIEW LETTERS 19 DECEMBER 1983

Observation of a Burst of Cosmic Rays at Energies above 7×10^{13} eV

D. J. Fegan and B. McBreen
Physics Department, University College Dublin, Dublin 4, Ireland
and
C. O'Sullivan
Physics Department, University College Cork, Cork, Ireland
(Received 14 Sept 1983)

The authors report on an unusual simultaneous increase in the cosmic-ray shower rate at two recording stations separated by 250 km. The event lasted for 20 s. This event was the only one of its kind detected in three years of observation. The duration and structure of this event is different from a recently reported single-station cosmic-ray burst. The simultaneity of the coincident event suggests that it was caused by a burst of cosmic gamma rays. There is a possibility that this event may be related to the largest observed glitch of the pulsar in the Crab Nebula.

PACS numbers: 94.40.Pa, 95.85.Qx, 97.80.Jp

Forgotten (!) treasure (?) no. 2

Correlated cosmic rays?

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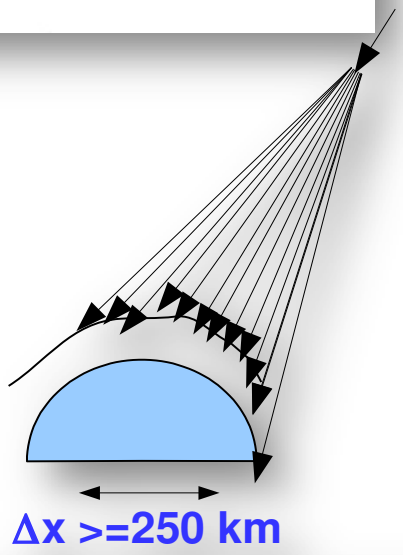

Example of CRE : Preshower near the Earth

Monte Carlo simulation chain

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(1) Simulation of eletromagnetic particle by interaction with geomagnetic field (Preshower effect)

(2) Simulation of shower in air at high zenith angles

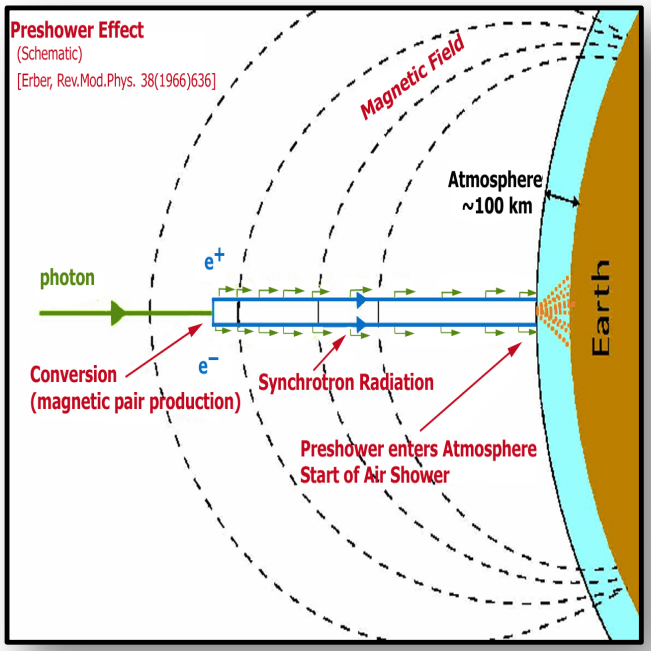
(3) Simulation of CTA responce

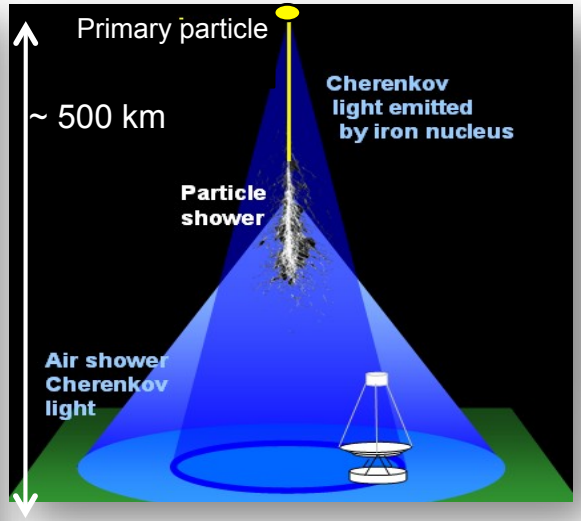
PRESHOWER → ***CORSIKA*** → ***Sim_telarray***

Homola et al., Computer Physics Commun. 184 (2005), 1468

D. Heck, et al., FZKA Report, 6019 (1998)

K. Bernlöhr, Astropart. Phys. 30 (2008), 149





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Miror optics/camera electronics simulations, with public ***Production-1*** **settings**