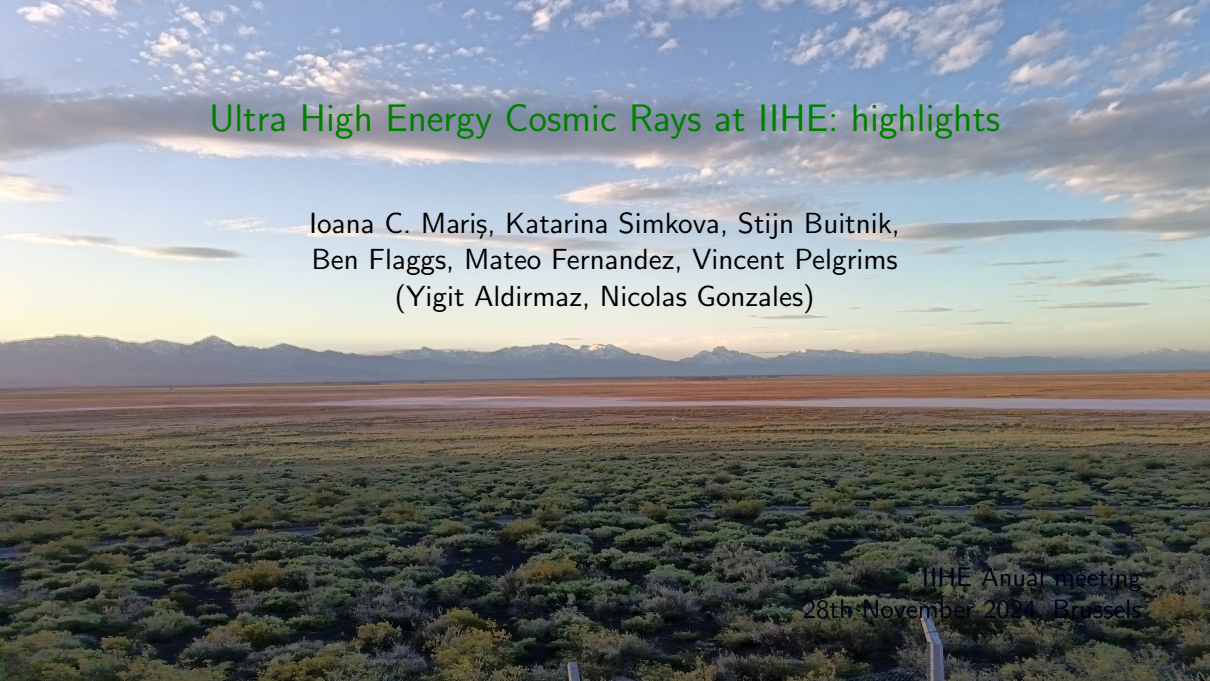
Ultra High Energy Cosmic Rays at IIHE: highlights

Ioana C. Mariș, Katarina Simkova, Stijn Buitnik,
Ben Flaggs, Mateo Fernandez, Vincent Pelgrims
(Yigit Aldirmaz, Nicolas Gonzales)



IIHE Anual meeting
28th November 2024, Brussels

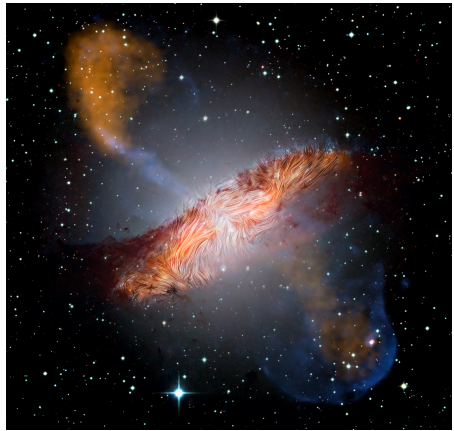
Most energetic particles in the Universe

Ultra-high-energy cosmic rays: Highest energy particles ever measured, above 10^{20} eV

Where do they come from?

How are they accelerated?

New fundamental physics?



... but also some of the most challenging to understand

Pierre Auger and Telescope Array collaborations advance in this quest in multiple direction

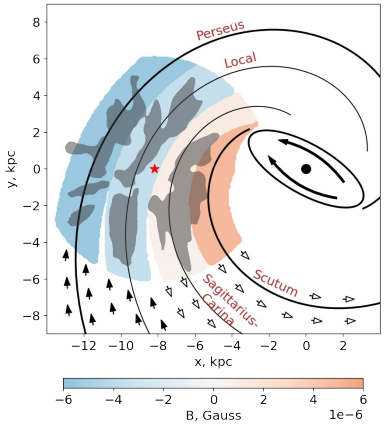
Our activities

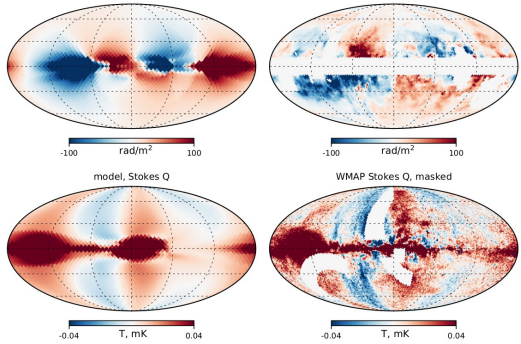
Phenomenology: magnetic fields modeling and UHECRs tracking

Data analysis: energy spectrum, mass composition, muon number

Combining everything: large scale anisotropies, point sources and photon searches

From the source to Earth: modeling the coherent magnetic field





- New model of the large-scale coherent Galactic magnetic field
- Improved treatement of statistical errors – greater sensitivity to the data
- Fitted to rotation measures of extragalactic sources and skymaps of polarized radio emission (WMAP)
- New important features: Fan Region, Local Bubble, larger pitch angle

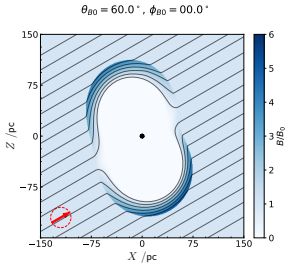
A.Korochkin, D.Semikoz, and P.Tinyakov
arXiv:2407.02148, **accepted to A&A**

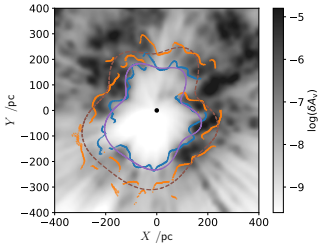
collaboration with Peter Tinyakov and Alexander Korochin

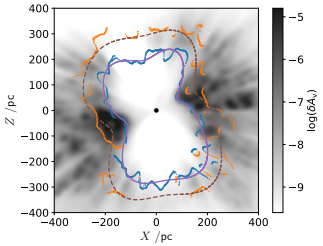
A more realistic Local Bubble

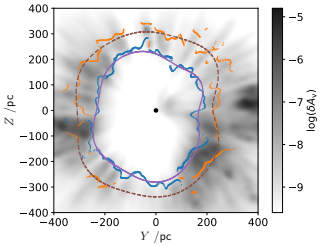
Theoretical model for the amplification and deformation of the magnetic fields by any supernovae-driven bubble

Use the dust density data to model the shape



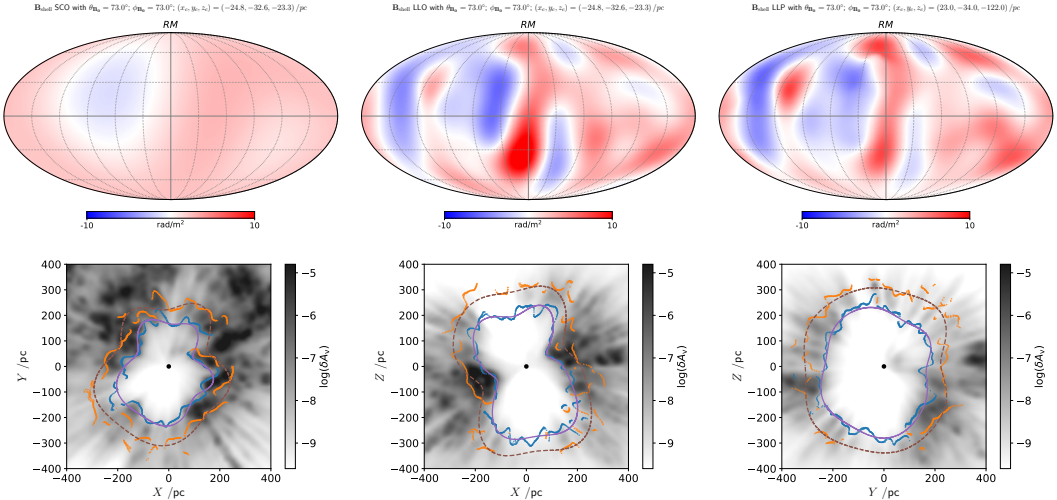






V.Pelgrims, M. Unger and I.Mariş, arxiv:2411.06277, submitted to A&A

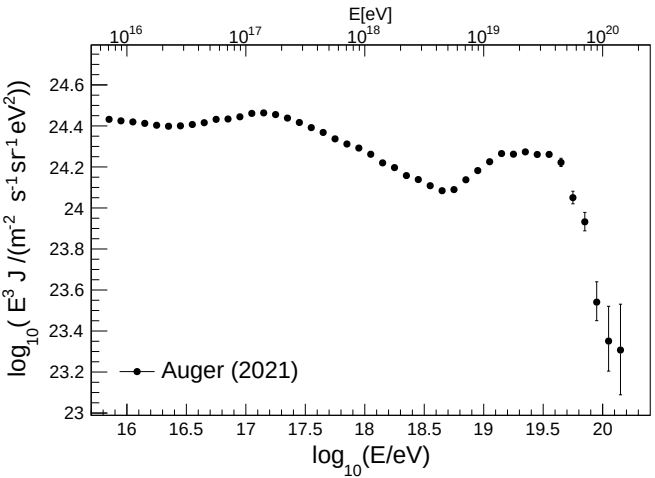
A more realistic Local Bubble



V.Pelgrims, M. Unger and I.Mariş, arxiv:2411.06277,submitted to A&A

On Earth: Air-shower measurements

... over more than 4 decades in energy



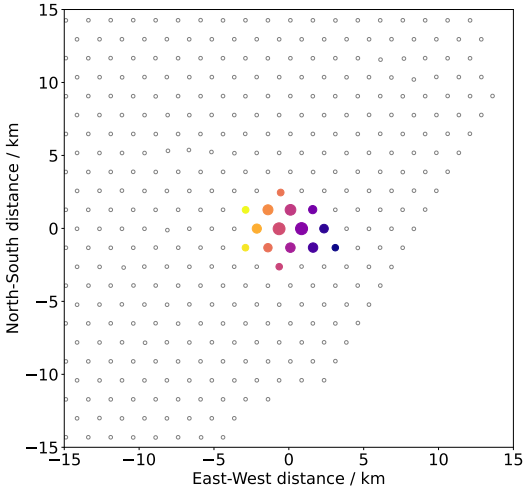
Accumulated statistics over 20-years of continuous operation with 3000 km^2 allow to observe the fine structures of the energy spectrum

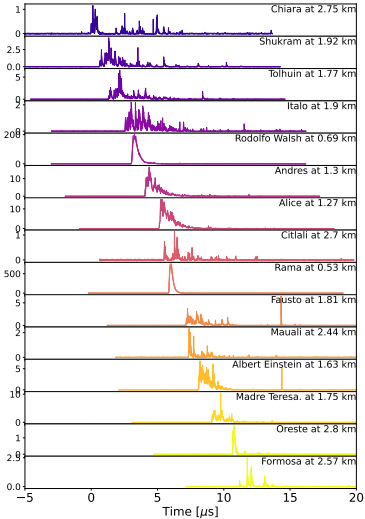
Auger coll., PRL 125 (2020) 121106,
Eur. Phys. J. C 81 (2021) 966
contributions from D. Mockler and I. Mariş

Measurements requirement: energy, arrival direction and mass

Examples of the higest energy events

Auger: 72 EeV, 36 degrees



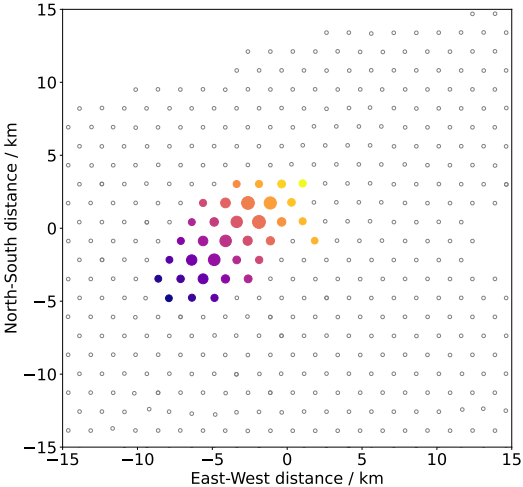


Auger coll. ApJS 264 50 (2023)

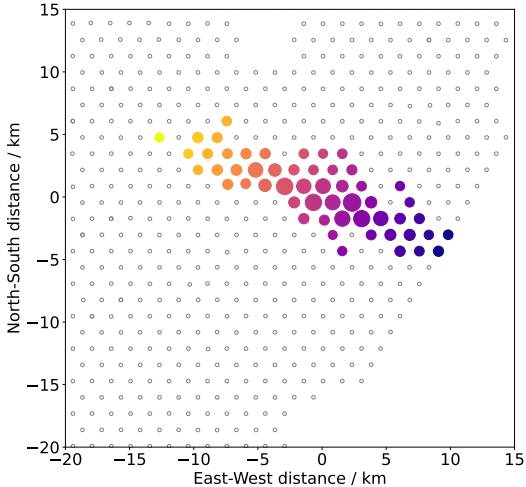
Time distribution of signals recorded to follow the detailed structure of the air-shower front

More inclined air-showers

Auger: 165 EeV, 59 degrees

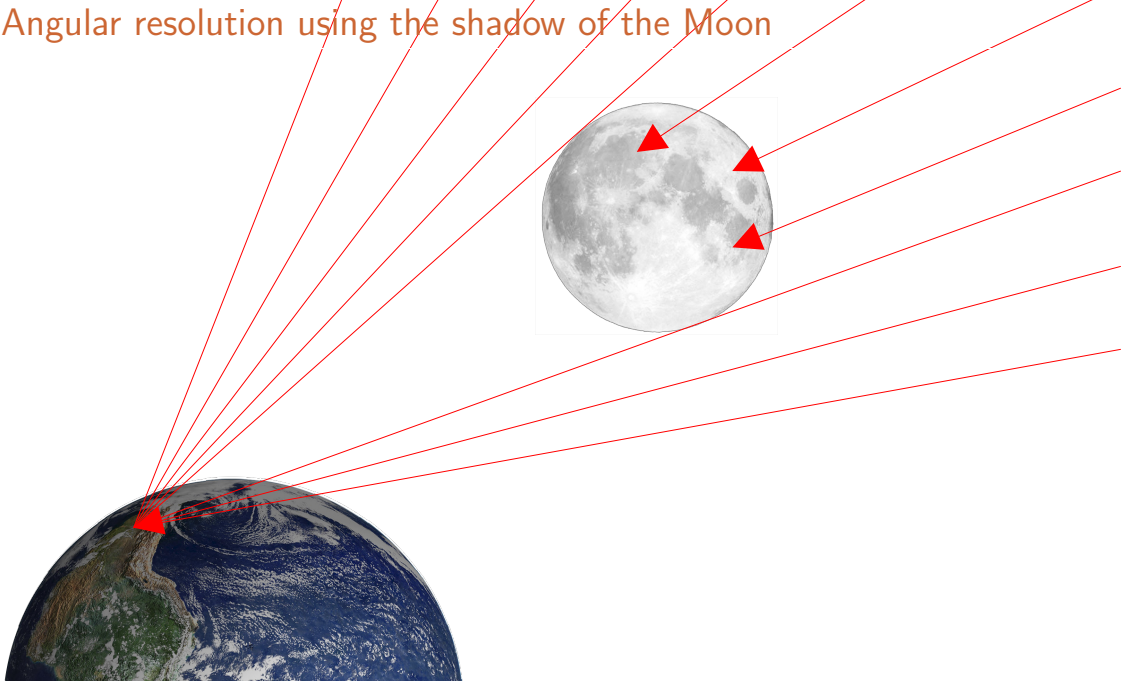


Auger: 50 EeV, 77 degrees



opendata.auger.org, 20/03/2024, release 3, DOI 10.5281/zenodo.10488964

Angular resolution using the shadow of the Moon



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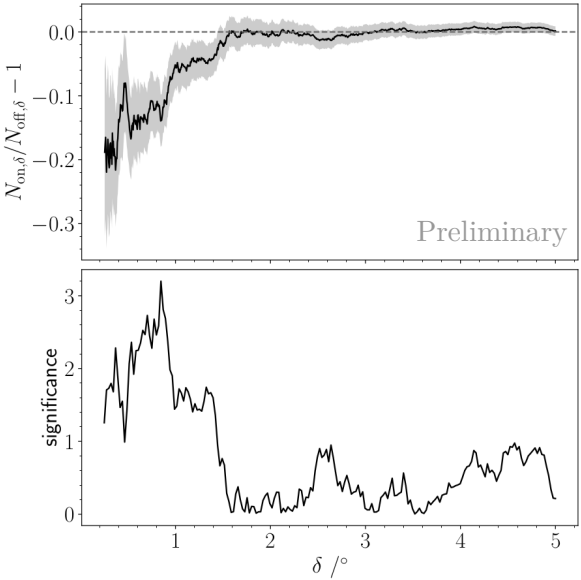
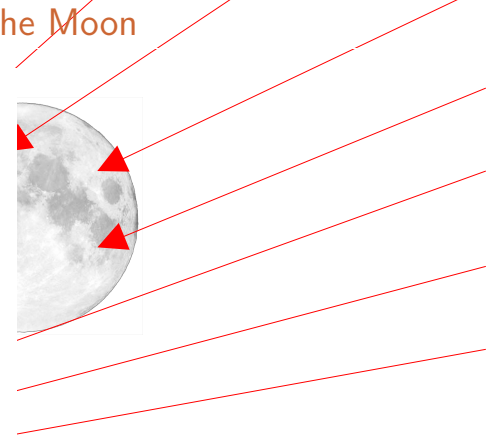


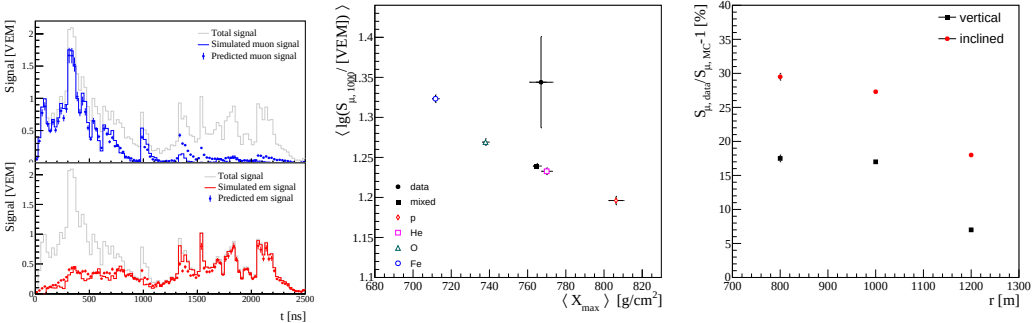


First estimation based on data of the effective angular resolution: better than 1 degree

K. Simkova (PhD, FWO funded),S. Buitnik, V. Pelgrims, and I. Mariș, GAP 2024_043, paper in preparation

Muon deficit and particle physics

Orazio Zapparata (defended in 2023), GAP2023_048



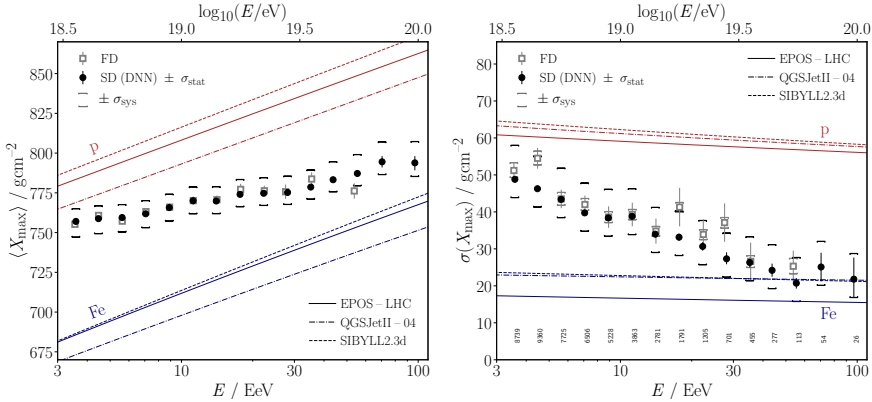
Extraction of the muon component based on deep neural networks, confirming the results from Auger coll., Phys. Rev. D 109, 102001 (2024) with an independent technique

First hint of a distance to the shower axis dependency of the muon deficit

Mateo Fenandez

Muon number is a key ingredient for mass composition and photon-hadron separation

Mass composition using deep learning

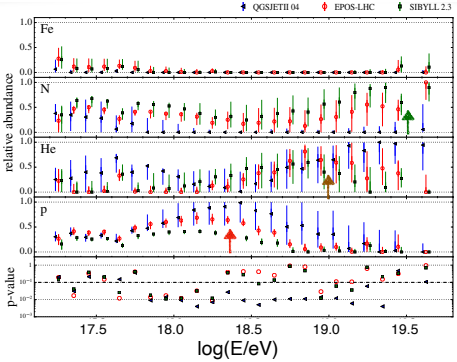


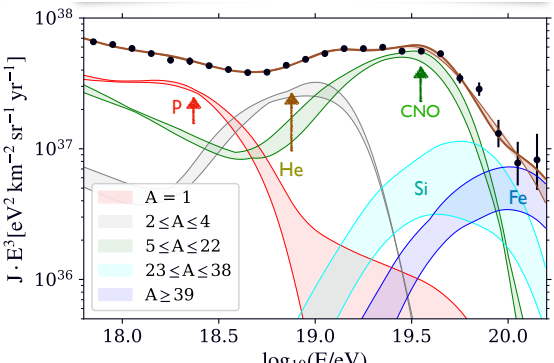
First measurement of the fluctuations of $X_{\max}$ up to 100 EeV using the surface detector, provides strong constrains on the source properties and expected UHE neutrinos fluxes

Auger coll., accepted to PRL and PRD, contribution from IM

Mass composition and energy spectrum

Combined fit of $X_{\max}$ and energy spectrum

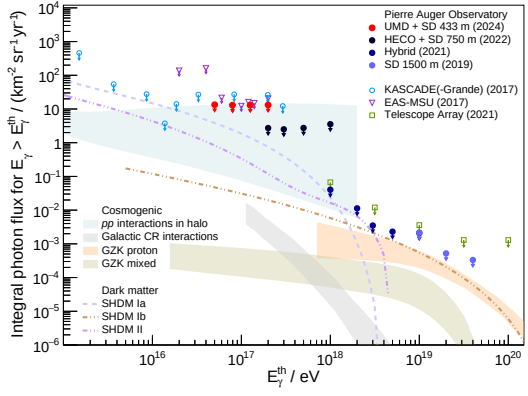




Source properties: rigidity $\log(R_{\max}) \approx 18.15$V $\rightarrow$ flux suppression dominated by the end of the UHECR spectrum, not by propagation

Assuming steady extra-galactic sources: very hard nuclear spectra escaping sources, not very good news for the cosmogenic neutrino predictions

Ultra-high-energy photons



Separation power better than 10^{-5}, limits obtained with a very small equivalent time of 6 months of data taking

Proof of principle: First application of the data from underground muon detectors to a physics analysis

N. Gonzalez and I.Mariş, Auger coll. to be submitted to JCAP

AugerPrime fully deployed and Auger Phase 2 starts

Celebration of the 10-years extension of the data-taking for the Observatory

FNRS signs the International Agreement

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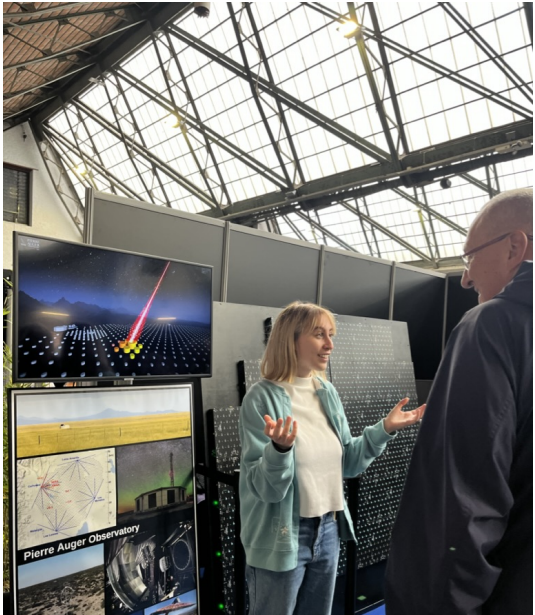
Outreach and responsibilities



Presentations at I love science festival, Masterclass (togetehr with IceCube), Printemps des Sciences

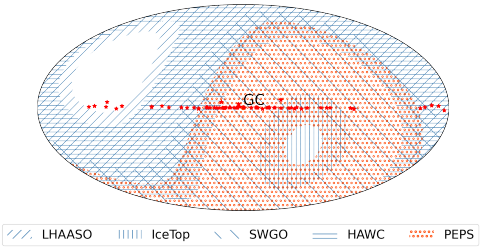
A.Caliktor, D.Deraed, M.Vandererven, M. Weil, Y.Allard, I. C. Maris,, P.Dewulf, and O.Zapparrata, "Design of an outreach dispaly of the Pierre Auger Observatory", GAP2024_28

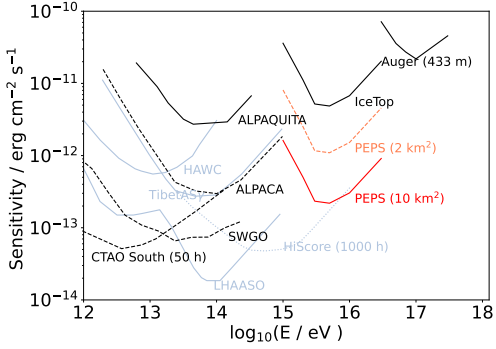
Responsibilities: chair of the publication committee, task leader of "Auger as test environment"

Laurent Favart: elected chair of the Finance Board

Future projects: Probing Extreme PeVatron Sources (PEPS)

Idea: build a 10 km^2 denser array in the same area as the underground muon detectors using double liner water-Cherenkov detectors (Phase I of 2 km^2 in the next years) in a cost effective and green way



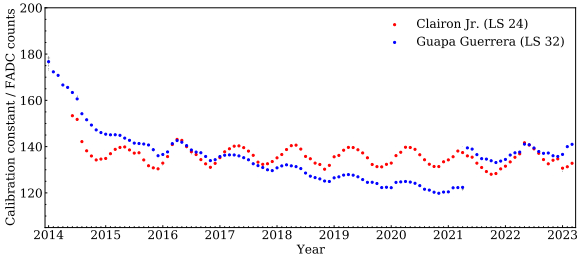


Reaching energies down to ≈1 PeV: Tens of events expected for similar sources as the ones observed by LLHASO with a very good coverage of the southern sky and of the galactic center.

Complementary to the current and future experiments

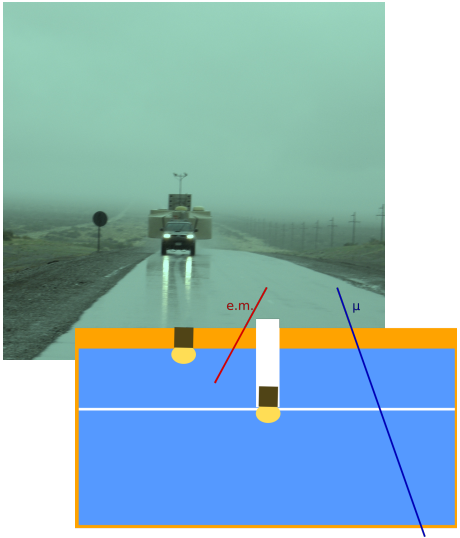
supported by Auger Collaboration (not an Auger project)

PEPS: Technology based on water-Cherenkov detectors

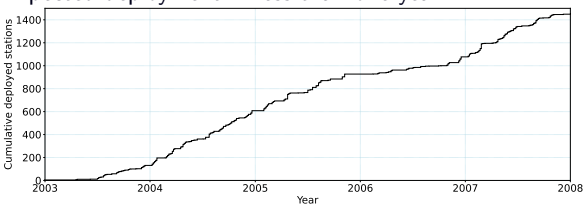


The two prototypes on the field functioning since 2014

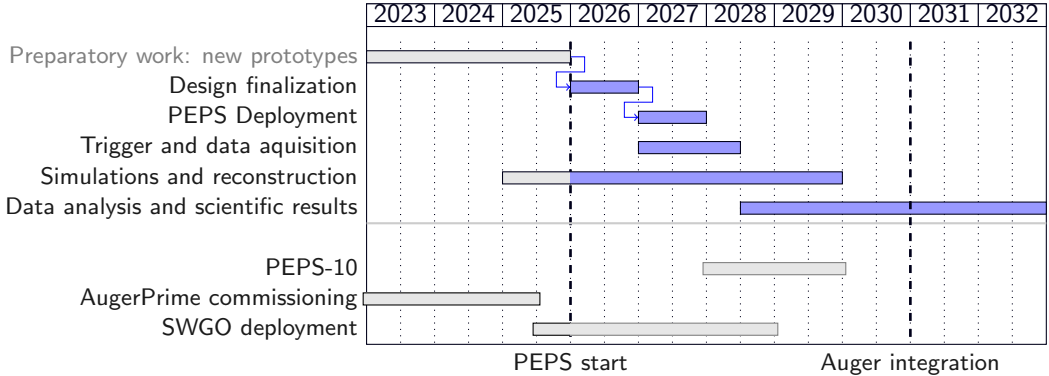
Ben Flaggs



Expected deployment in less than one year



When and how?



In 2025: extend to a full double liner hexagon with 3 more detectors

Not only science...