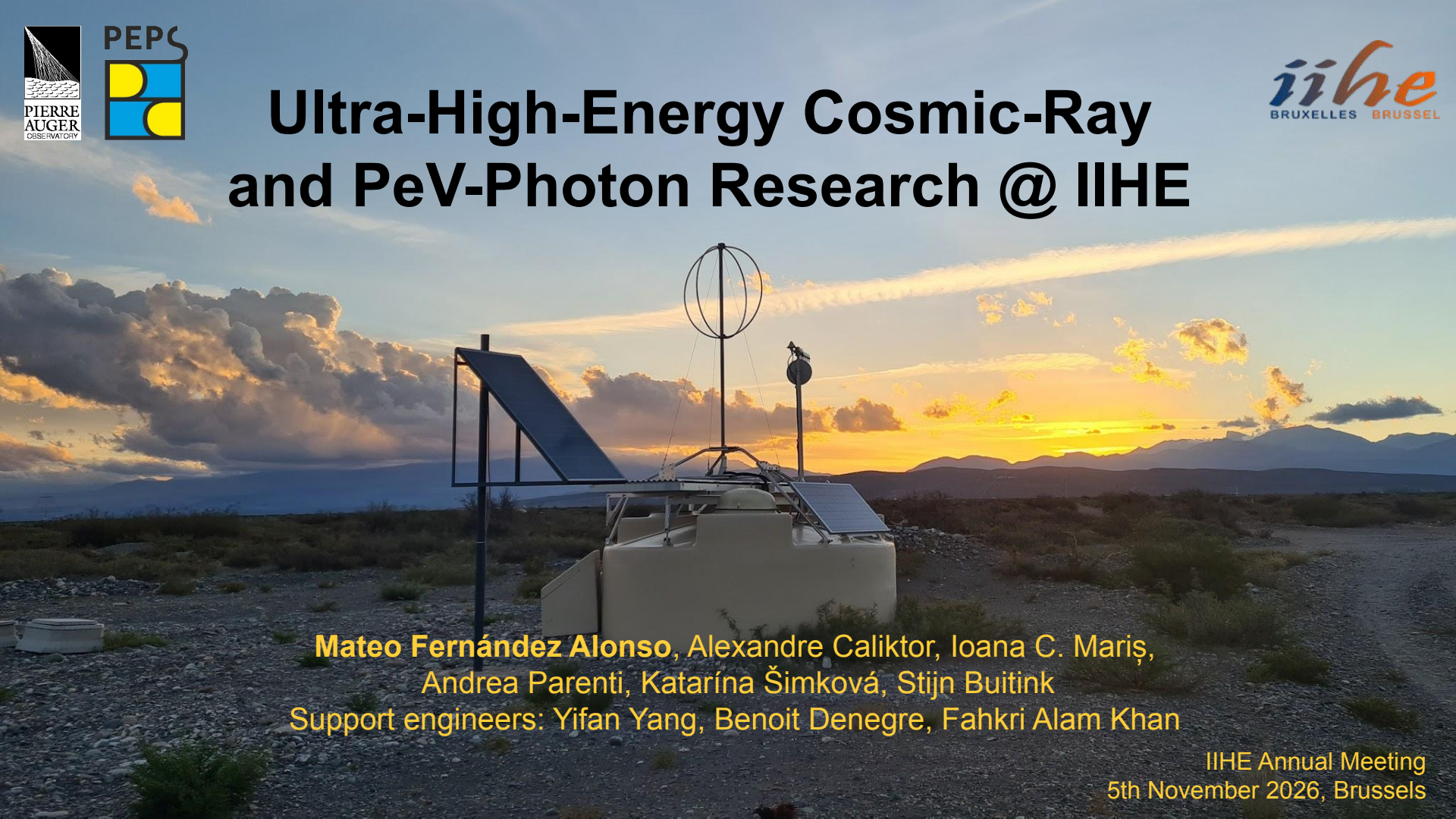
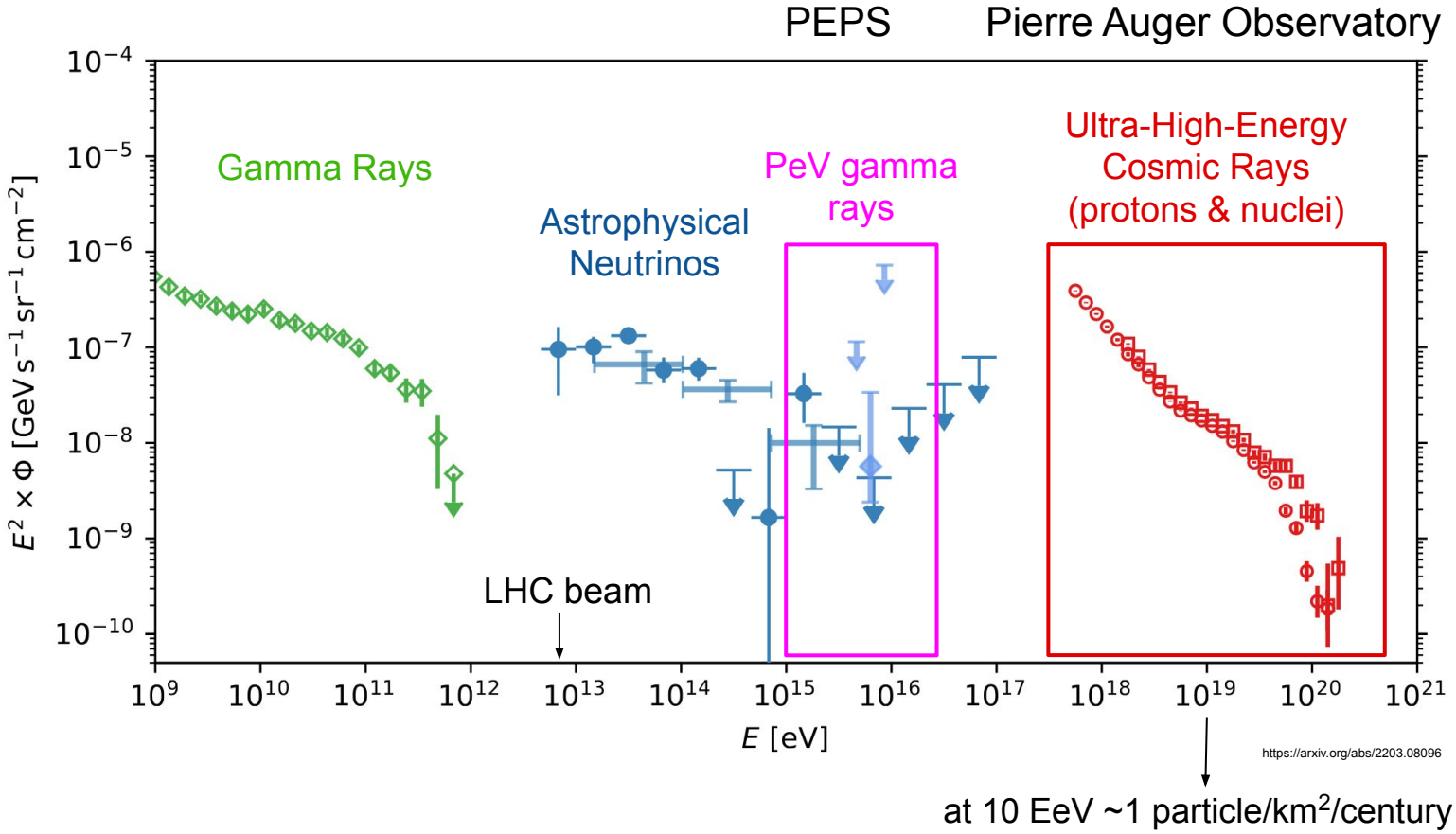
Ultra-High-Energy Cosmic-Ray and PeV-Photon Research @ IIHE



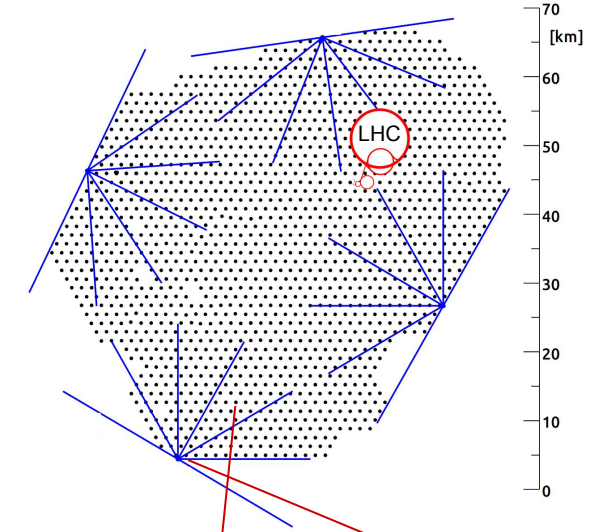
Mateo Fernández Alonso, Alexandre Caliktor, Ioana C. Mariș,
Andrea Parenti, Katarína Šimková, Stijn Buitink
Support engineers: Yifan Yang, Benoit Denegre, Fahkri Alam Khan

IIHE Annual Meeting
5th November 2026, Brussels

Our group is interested in the highest-energy particles

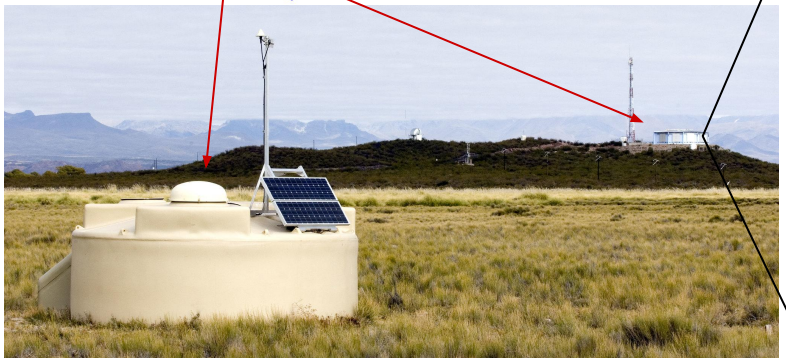


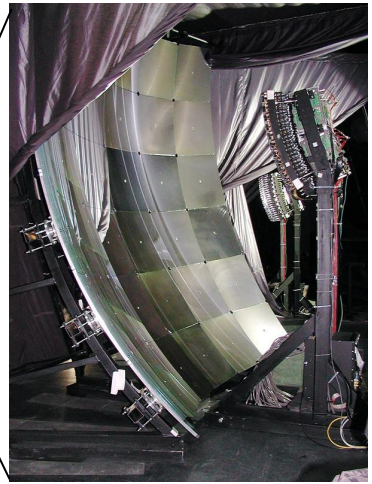
The Pierre Auger Observatory (Malargue, Argentina)



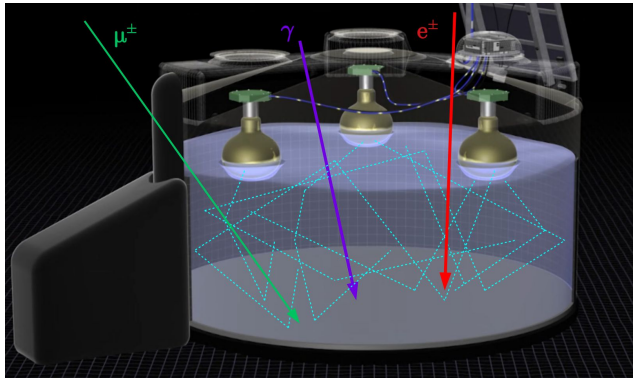
Covers 3,000 km^2 with 1600 detectors
Operational since 2004 (at IIHE since 2018)

Major upgrade commissioned in 2025: installation of scintillators and radio antennas (new enhanced data to analyse!)





Water Cherenkov Detector (WCD)



Some of the answers to the origin and nature of UHECRs

Spectrum above 10^{16} eV - features (second knee, ankle, cutoff..) trace propagation and acceleration of these particles

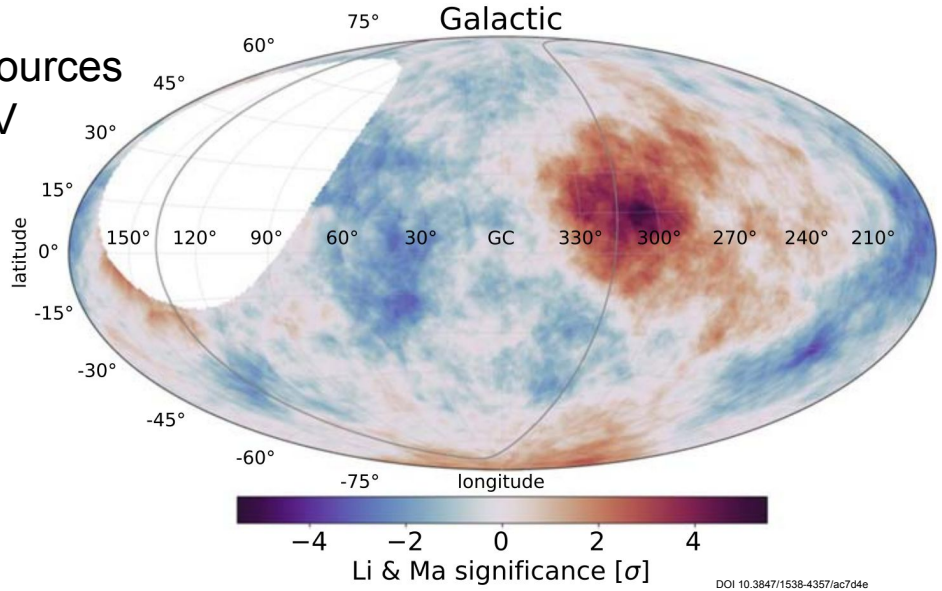
Composition heavier towards highest energies → maximum possible acceleration energy?

Anisotropies:

- 6.8σ Dipole above 8 EeV → extragalactic sources
- 4σ Excess in Centaurus region at E>32 EeV

Remaining questions:

- Muon puzzle ($\mu_{obs} > \mu_{sim}$)
- What class(es) of sources?
- What acceleration mechanisms?

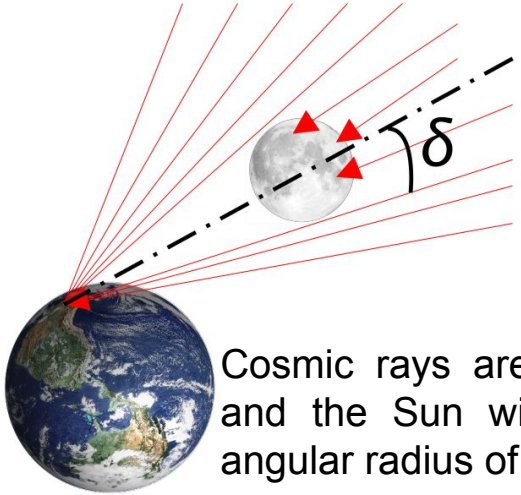


How accurate do we estimate the arrival direction?



T. Sandstrom, https://ar5iv.labs.arxiv.org/html/1512.00051

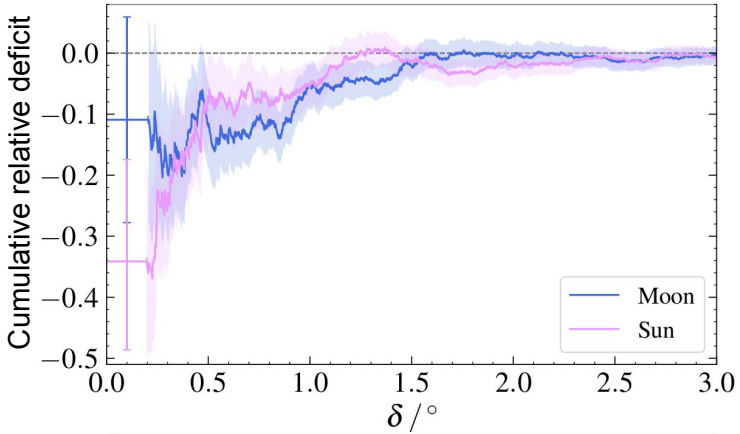
Evidence for the shadows of the Moon and the Sun above 10^{16} eV

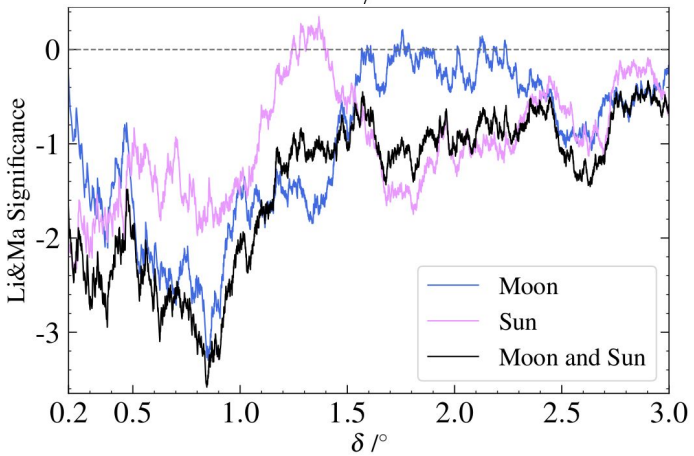


Cosmic rays are blocked by the Moon and the Sun with known position and angular radius of ~0.26°

Correct pointing and the effective angular resolution better than 1°

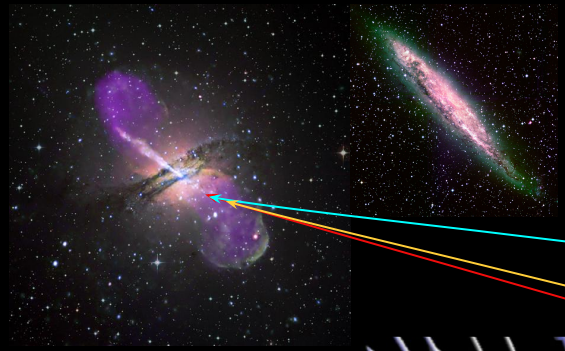
Unbinned likelihood fit significance of 3σ





Katarina, Auger full author list paper submitted to PRD: https://arxiv.org/abs/2608.04658

Magnetic fields deviate UHECRs blurring their arrival directions
→ but higher energy and smaller charge lead to smaller deviation



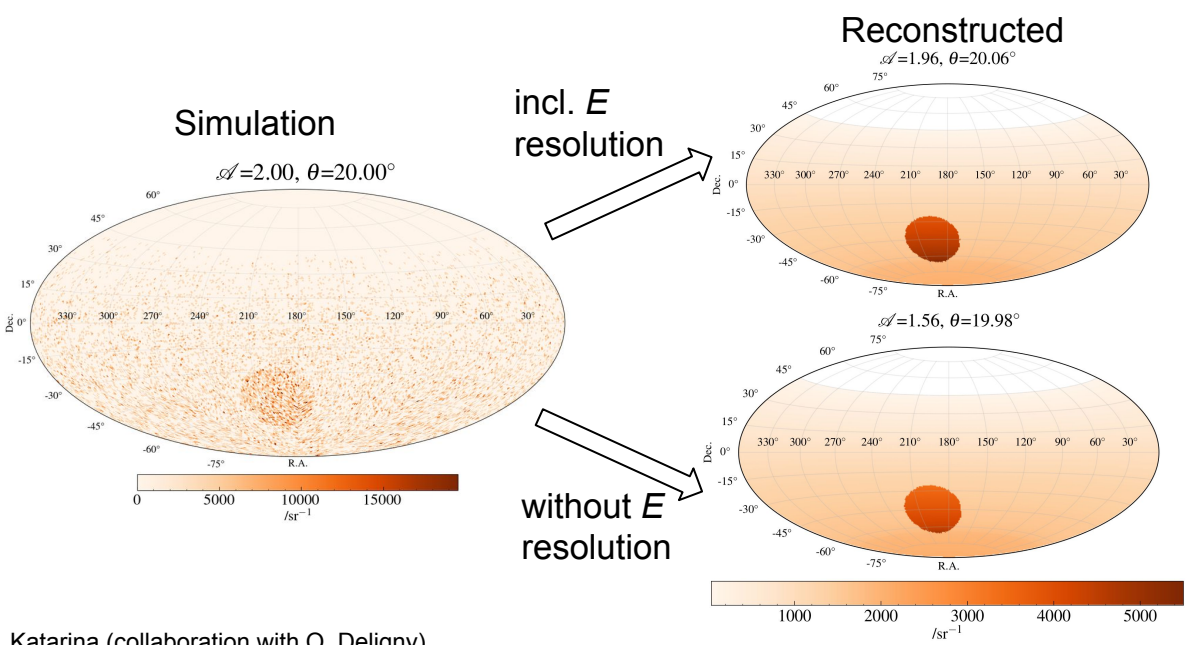
T. Sandstrom, https://ar5iv.labs.arxiv.org/html/1512.00051

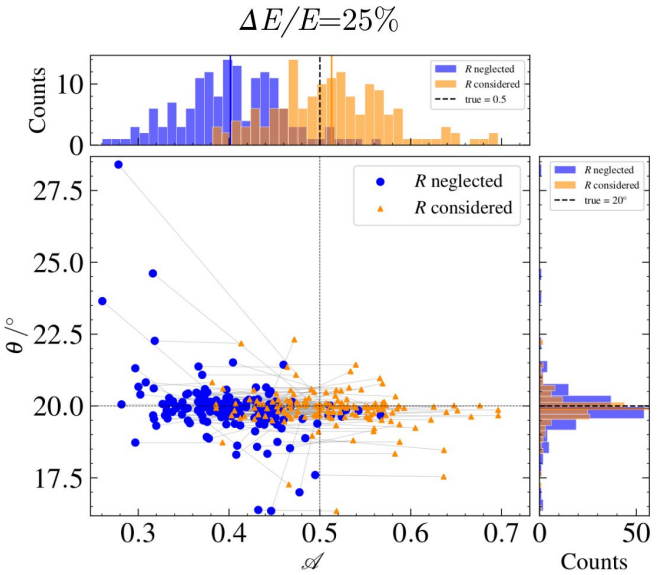
Including the resolution on mass-enhanced anisotropy studies

The detector resolution affects the reconstructed amplitude of the excess, due to the finite resolution of the selection variables: the energy, E_{rec} , and mass-sensitive variable, $X_{max,rec}$

Development of a likelihood to include the detector effects in the excess reconstruction

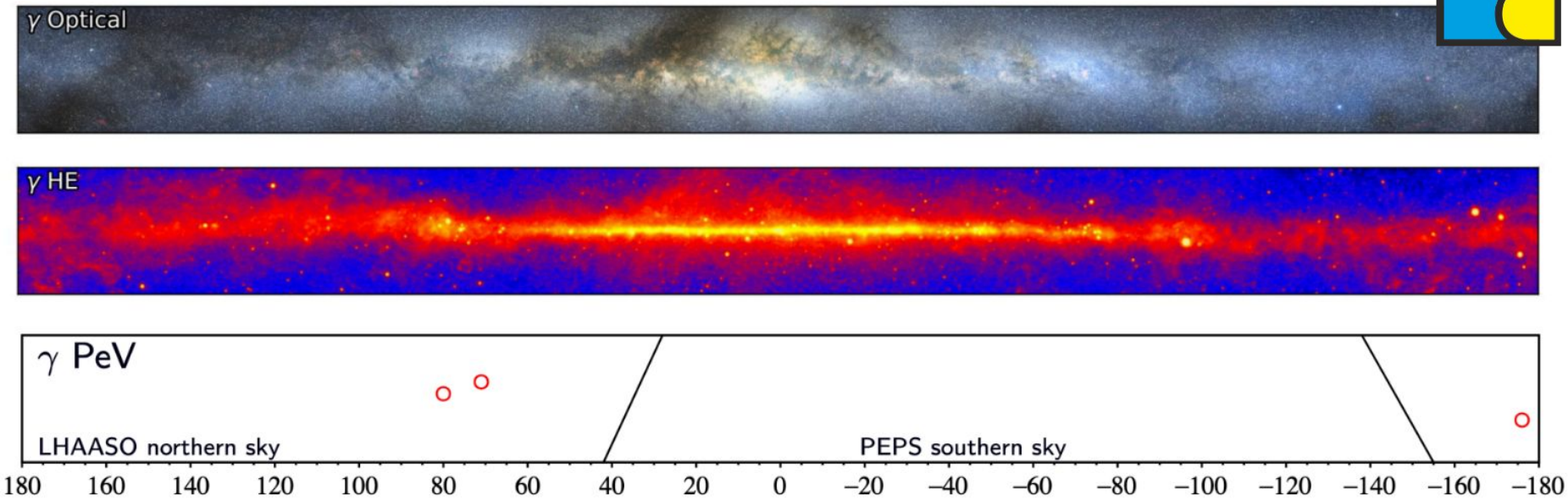
Preliminary results from simulations: we can recover the true amplitude of the excess





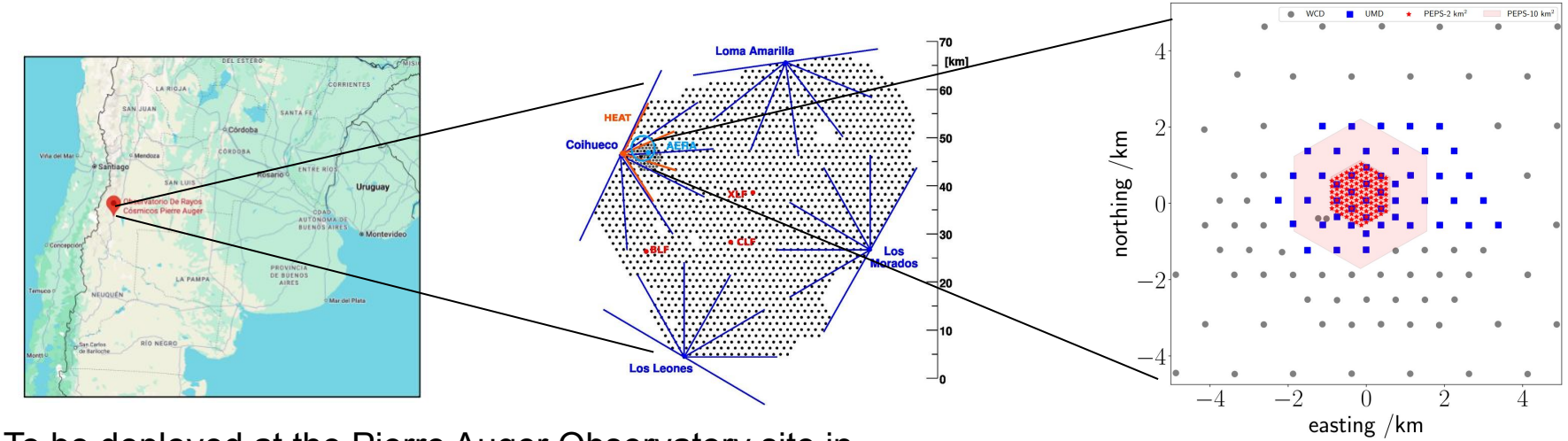
Katarina (collaboration with O. Deligny)

Probing Extreme PeVatron Sources (PEPS)



PEPS in the Southern hemisphere: 10 km2 array designed to measure gamma rays above 1 PeV

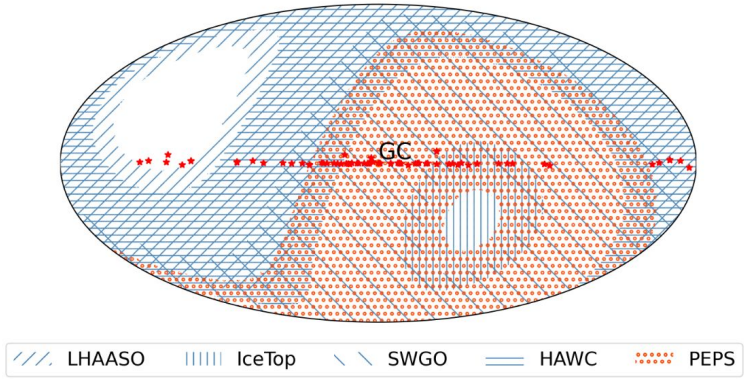
Excellent coverage of the southern sky



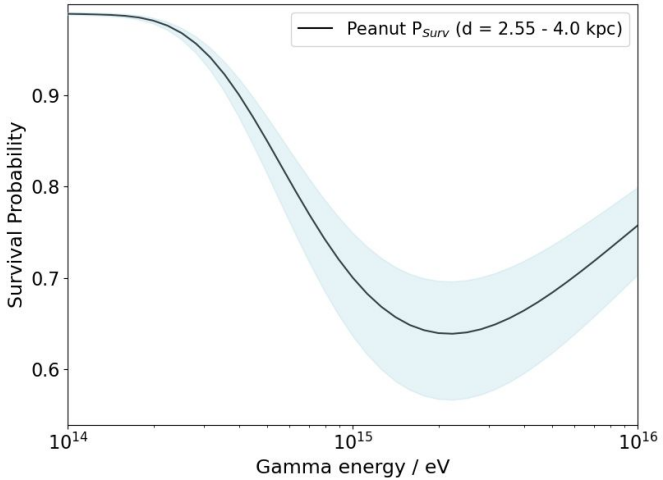
To be deployed at the Pierre Auger Observatory site in Mendoza, Argentina

FoV: excellent coverage of the Galactic Center & Galactic Plane

Complementary with LHAASO/HAWC with an overlap with future projects aimed at lower energies like CTA-S, SWGO and ALPACA

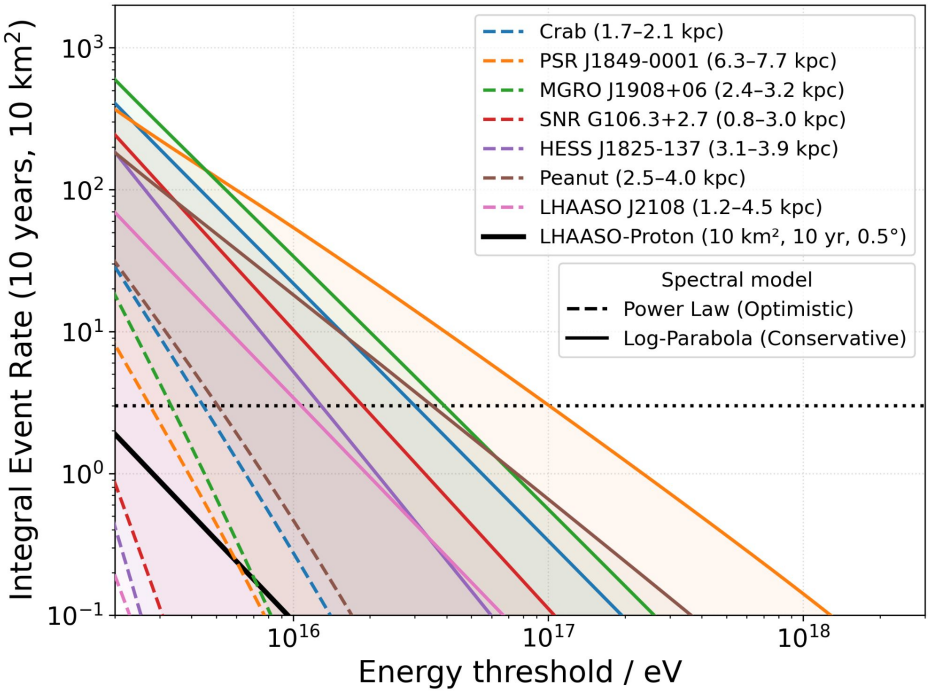


Examples of theoretical calculations



Estimations of the the expected number of events: extrapolate the measured spectra in an optimistic or conservative mode and take into account the gamma-gamma interaction.

Ioana and O. Angunher



Sensitivity calculation for the lifetime of super-heavy dark matter
Limits for the Lorentz invariance (Alexandre)

Towards PEPS deployment

PEPSino (in the next years)

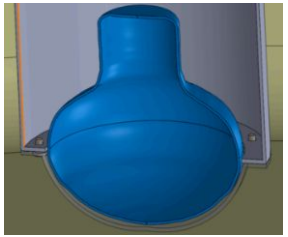
- Plans to deploy a 8 stations
- Preparation and tests of components in Brussels
- Cost-effective: using old Auger electronics
- First 2 detectors installed at Auger in 2014

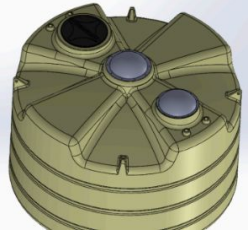
Array density: 55 stations/km^2

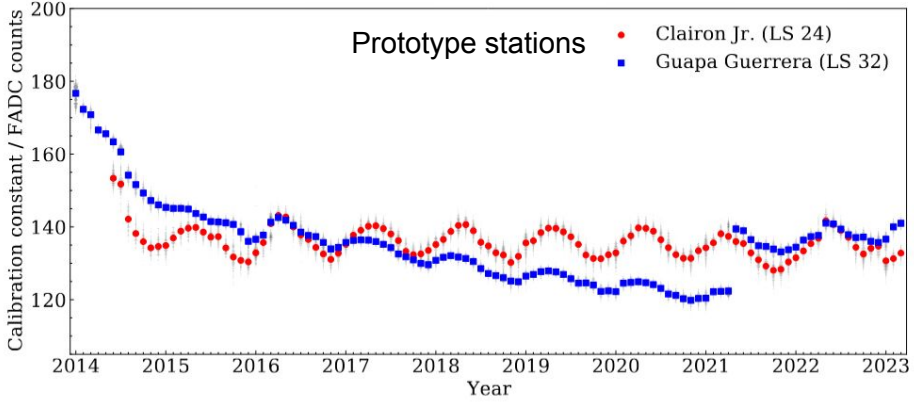
Test-prototype for next-generation UHECR observatories (GCOS)

Hardware development at IIHE: Mateo, Ioana, Yifan, Fakhri and Benoit





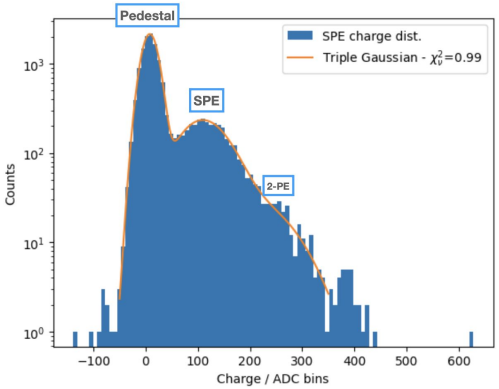


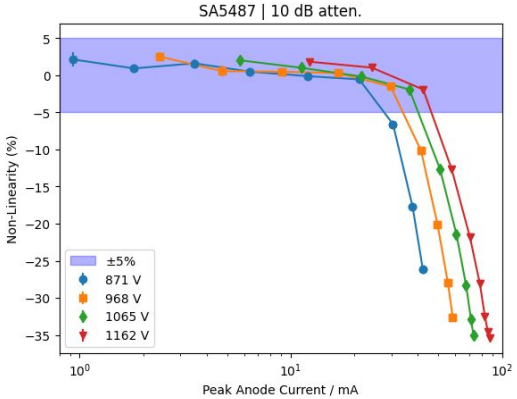


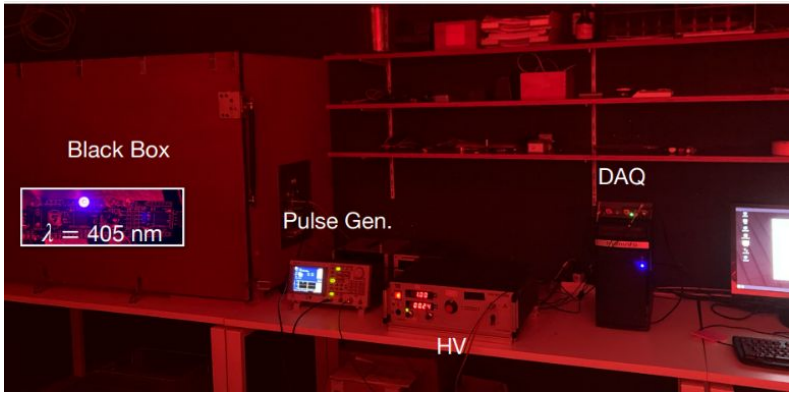
P. Billoir, B. Flaggs, I. Maris and A. Parenti, PoS-ICRC2025-354

Technical developments for PEPS in Brussels

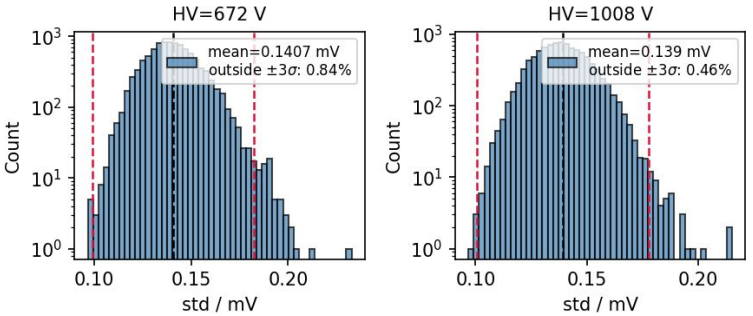
Characterization and testing of PMTs, PMT base and electronic board (UB) integration



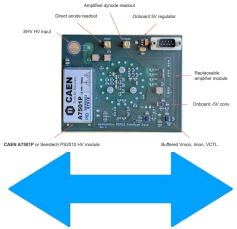


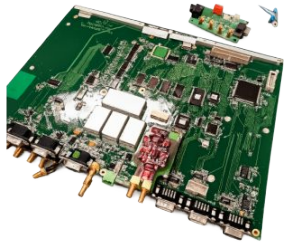


Baseline std distributions (head), channel Anode









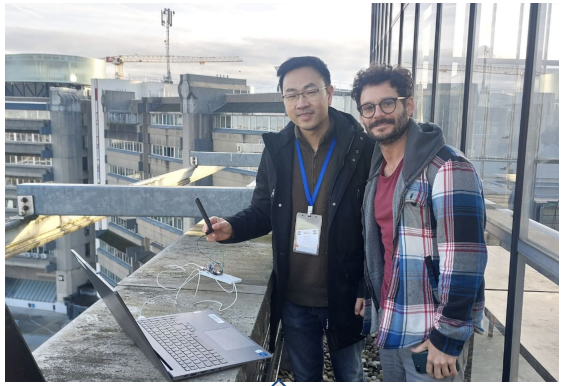
Technical developments for PEPS in Brussels

Communication system development and tests

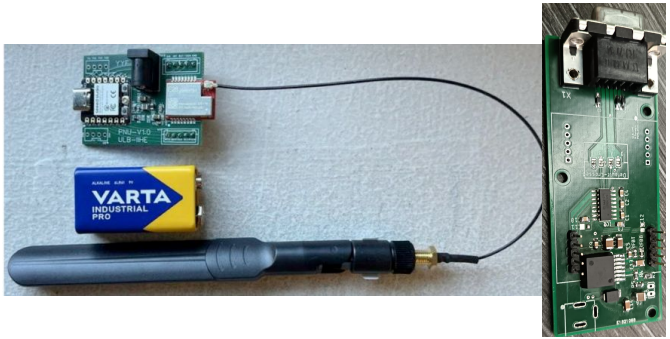
Currently adapting and testing off-the-shelf communication systems

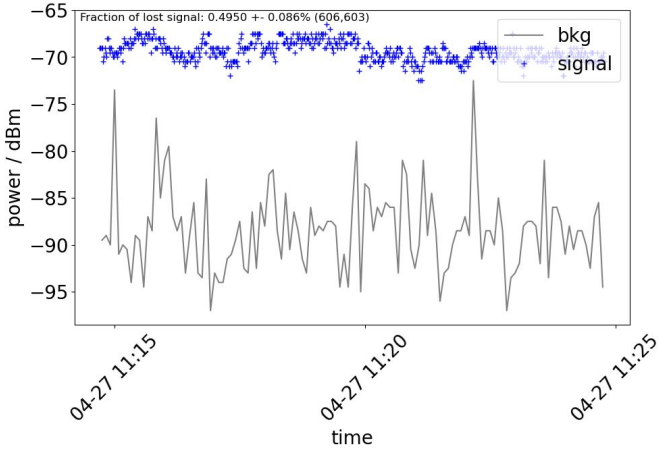
UB compatibility

Investigating data transfer, performance, power consumption, etc.







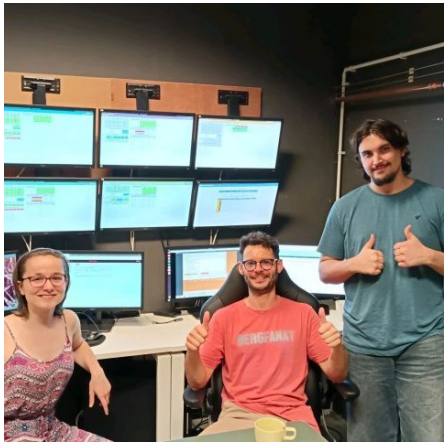


Pierre Auger FD Shifts

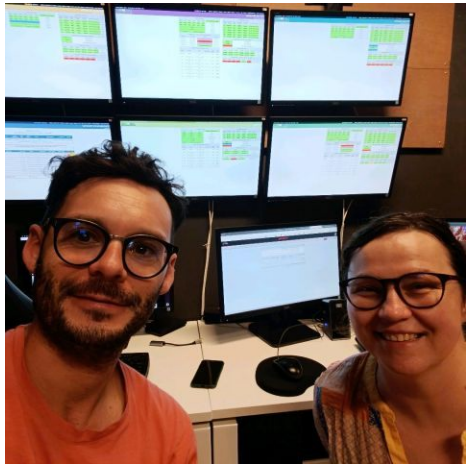
This year the IIHE team covered two FD shifts in June and September totalling 130 hours

The shifts are essential for the operation and proper data taking of the FD

Good opportunity for students to get a first-hand experience with the observatory’s operations









Responsibilities, outreach and workshops





Responsibilities:

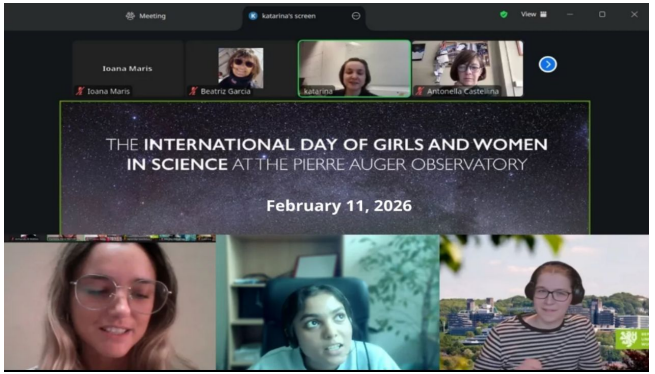
Katarina: Auger Early-Career Representative (2025-26)

Ioana: ex-chair of the Auger Publication Committee, Task leader of "Auger as test environment", co-director of the CosPa network, member of the APPEC SAC,...

Laurent Favart: Chair of the Finance Board of Auger

Ioana & Katarina co-organizing Auger diversity sessions

3 PEPS Workshops organised (4th edition in 01/2027)



Outreach:

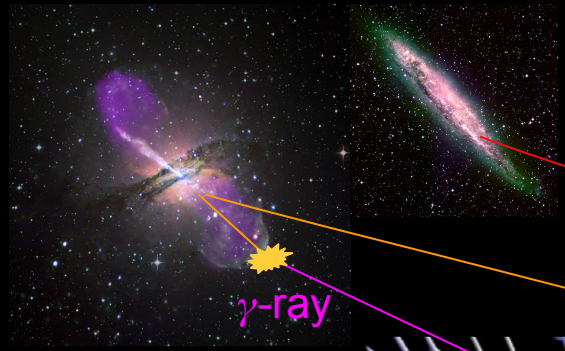
Feria de Ciencia: ULB bags to be taken to young high-school students in Malargüe

Strong contribution to Auger outreach activities and social media



IIHE Annual Meeting
5th November 2026, Brussels

Production sites of cosmic rays (CRs) can also produce photons in hadronic interactions, or photons can be produced during CR propagation



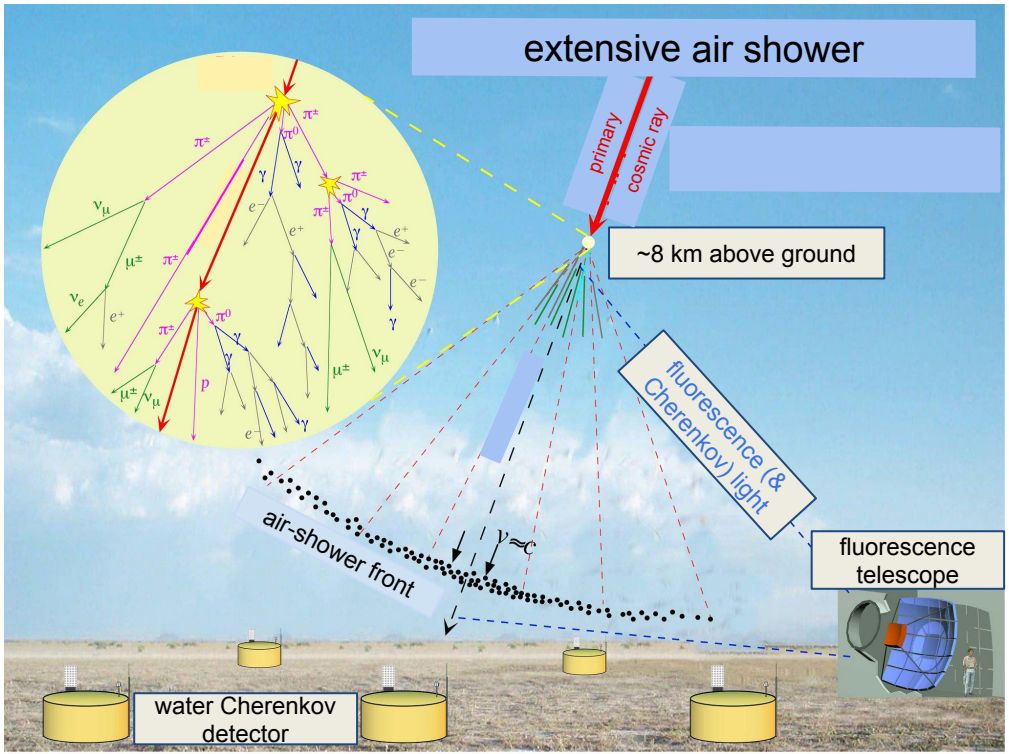
$\vec{B}$

T. Sandstrom, https://ar5iv.labs.arxiv.org/html/1512.00051

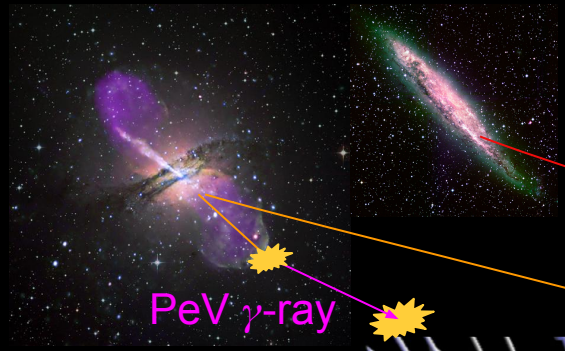
The Pierre Auger Observatory

World's largest cosmic-ray observatory spanning 3,000 km^2 in Mendoza, Argentina
Operational since 2004, Auger group started at IIHE in 2018





CR production is physically linked to VHE/UHE gamma-ray production. Only galactic PeV photons are expected due to absorption.



PeV γ-ray

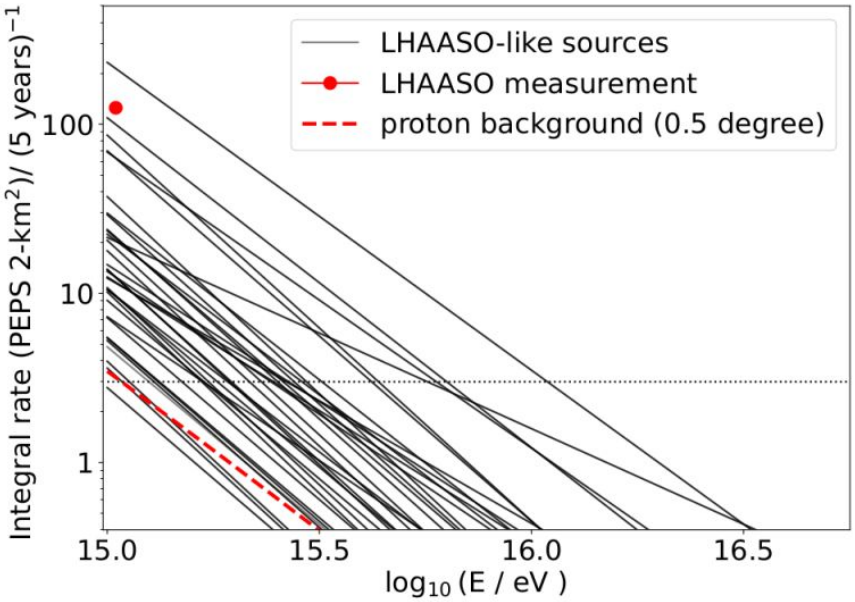
$\vec{B}$

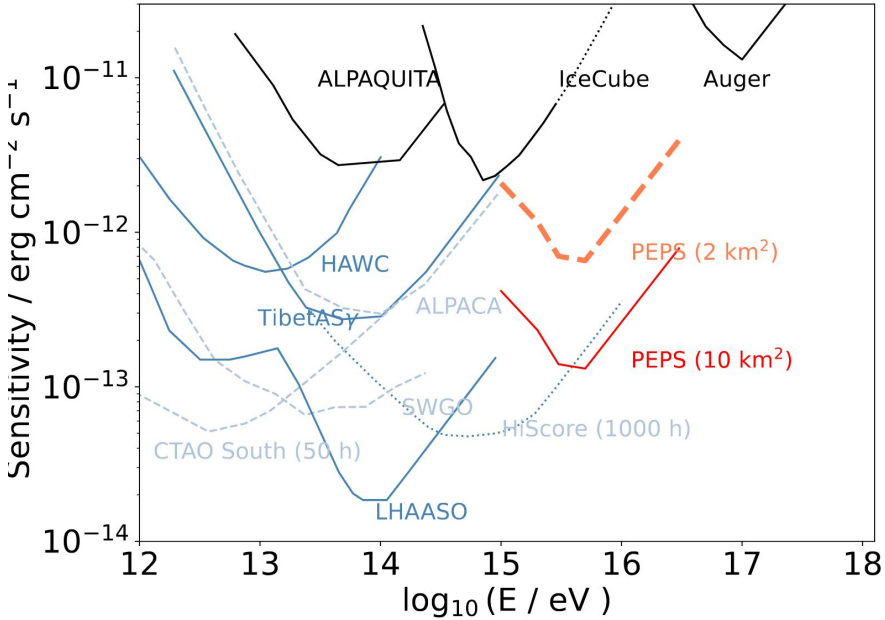
?

PeV γ-ray

T. Sandstrom, https://ar5iv.labs.arxiv.org/html/1512.00051

How many gamma rays we expect?





LHAASO measures around 25 photons/year above 1 PeV

Layered water Cherenkov detector to estimate muon signal

