Probing Extreme PeVatron Sources
PEPS

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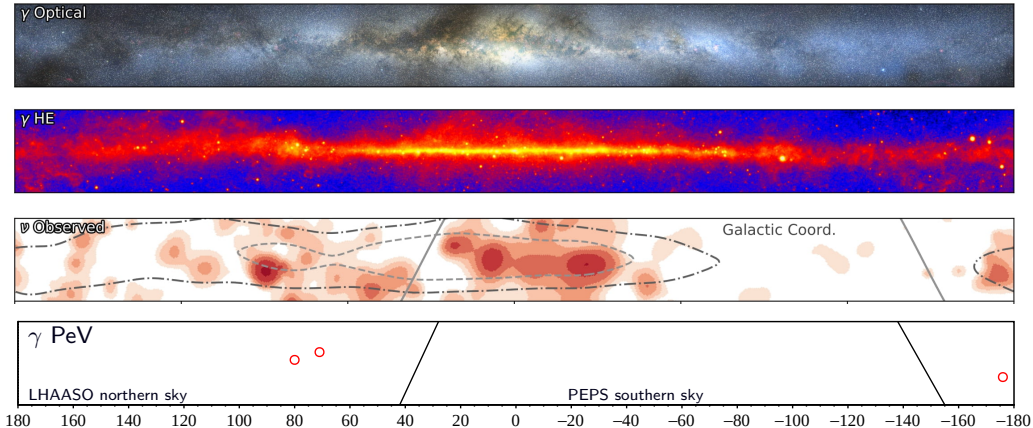
Université Libre de Bruxelles

14th CosPa meeting, Brussels

PEPS: Breaking the energy frontier

$10\,\mathrm{km}^2$ detector to measure gamma-rays between 1 PeV and 50 PeV

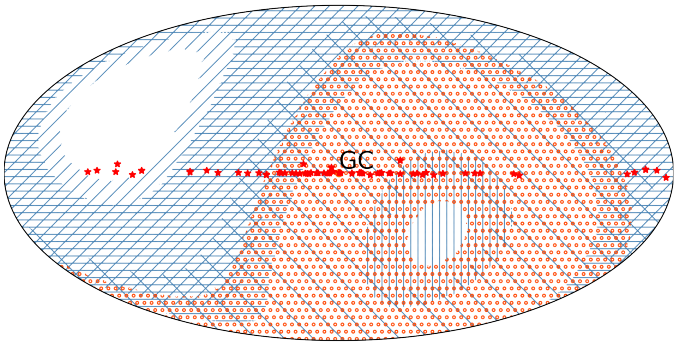


Discovery potential in the new energy range with
a unique view of the Galactic Center and southern galactic sky!

Looking at the southern sky for extreme galactic sources

At the Pierre Auger Observatory

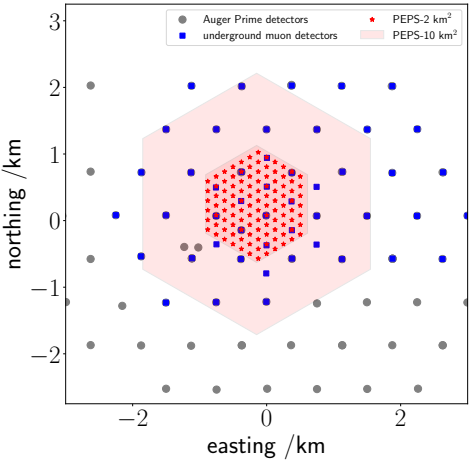
Complementary with LHAASO/HAWC and a good coverage of the Galactic plane and Galactic Center. Good overlap with SWGO/ALPACA (measuring at lower energies)

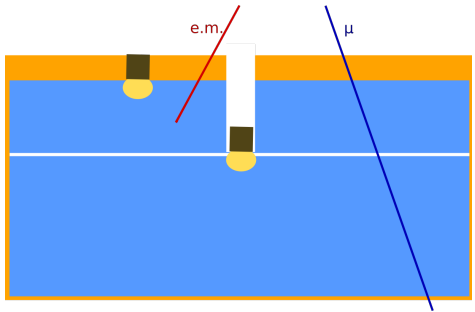


red points: TeVCat sources (tevcat.org)

Aim and approach

PEPS Phase I: a 2-km^2 surface detector of water-Cherenkov detectors





Layered Water Cherenkov detectors optically separated

(A. Letessier-Selvon, P. Billoir, M. Blanco, ICM, M. Settimo, NIM A767 (2014), arxiv:1405.5699)

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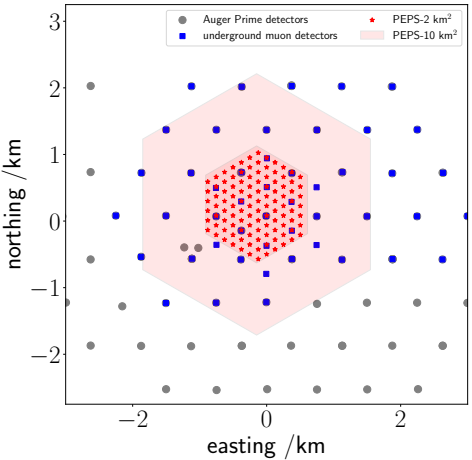
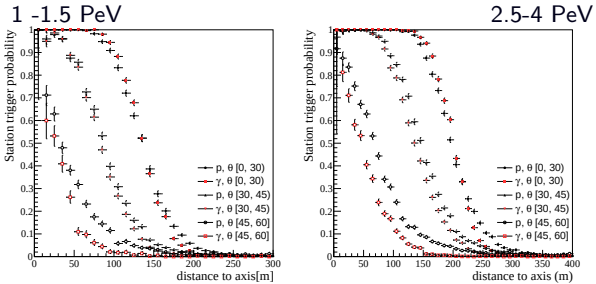


Corsika/EPOS-LHC, Geant4



An array with a spacing of 145 m between the detectors

prod. of simulations by N. Gonzalez and E. Santos

Aim and approach

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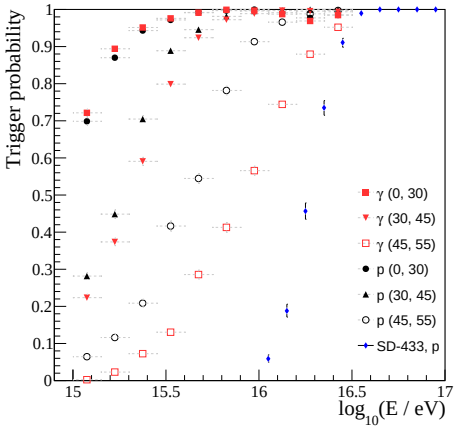
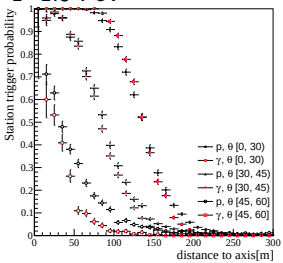
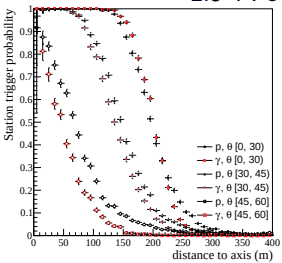


1 -1.5 PeV



2.5-4 PeV



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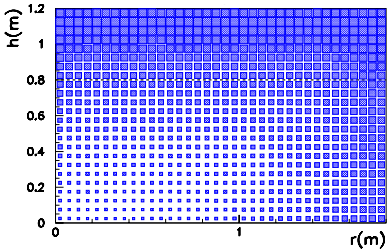
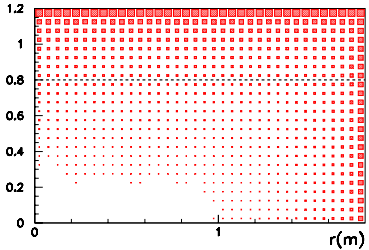
Proton/photon separation with a segmented water Cherenkov Detector

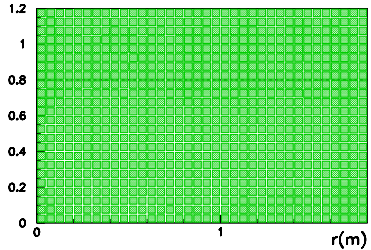
photons

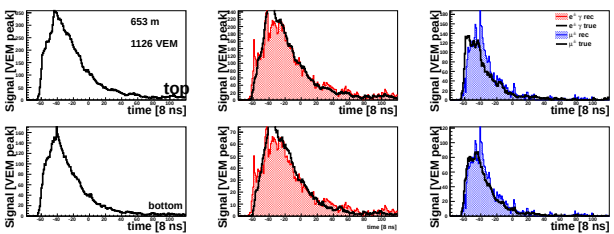


electrons



muons





A water volume responds different to photons, $e^{\pm}$ and $\mu^{\pm}$

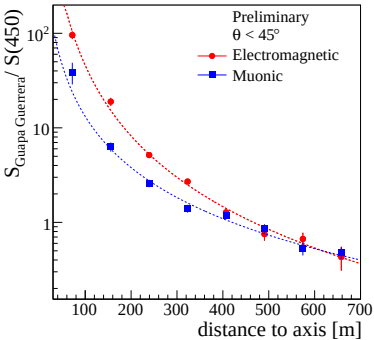
$$\begin{pmatrix} S_{\text{top}} \\ S_{\text{bot}} \end{pmatrix} = \begin{pmatrix} a & b \\ 1-a & 1-b \end{pmatrix} \begin{pmatrix} S_{\text{EM}} \\ S_{\mu} \end{pmatrix}$$

Obtain the muonic signal based on the differences between the traces

A. Letessier-Selvon et al., NIM A767 (2014)

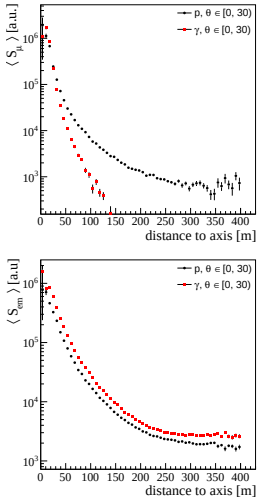
Photon-proton separation

Data from prototypes

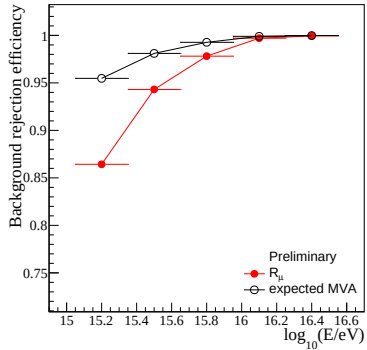


Average LDFs with two months of data in 2014 (E>10 PeV)

simulations



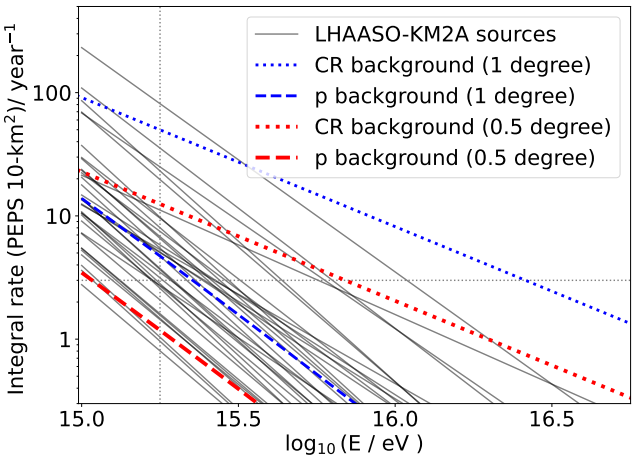
at 50% photon efficiency



Basic separation variables, summed over N stations (not optimized):

$$R_\mu = \frac{1}{N}\sum_i^N S_\mu \cdot r^{1.5}$$

Discovery of extreme PeVatrons in the Southern sky?
What is the maximum available energy in our Galaxy?



Extrapolations of the LHAASO sources

Between 30 and 400 events/ year above 1 PeV

Between 1 and 100 events/ year above 3 PeV

Background depends on the angular resolution (expected between 0.3 to 1 degrees) and separation power (this plot, 3e-4). RNN expected to improve sensitivity (O.Zapparata, PhD thesis, Auger coll., JINST 16 (2021) P07016)

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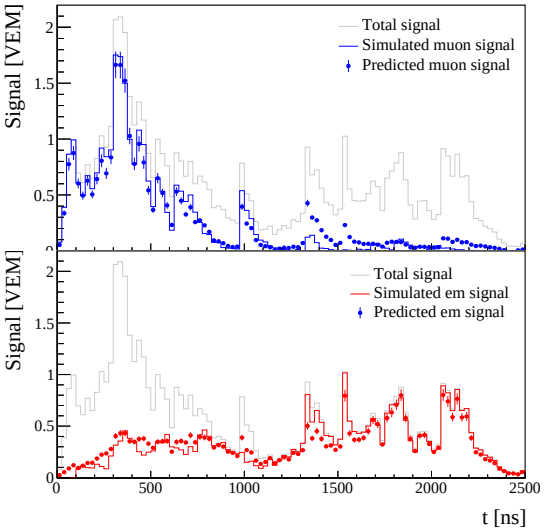

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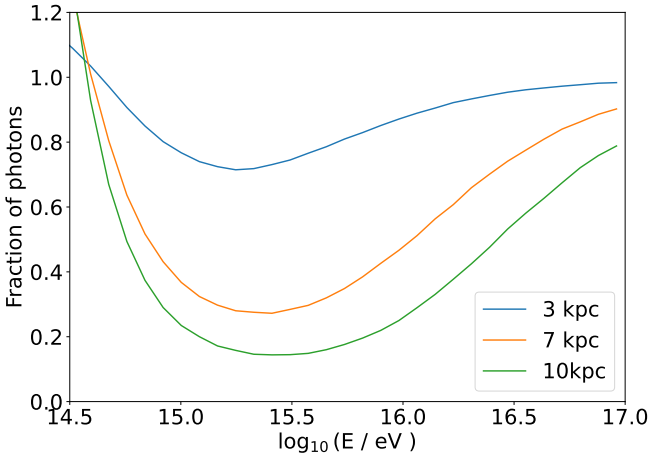

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γ-γ interactions important at distances larger than 5 kpc

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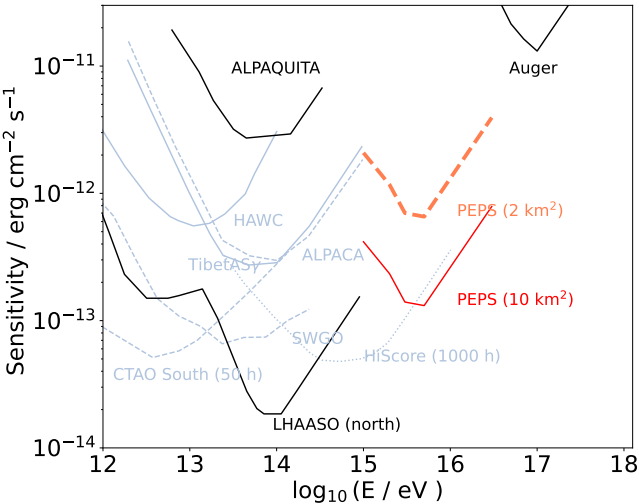

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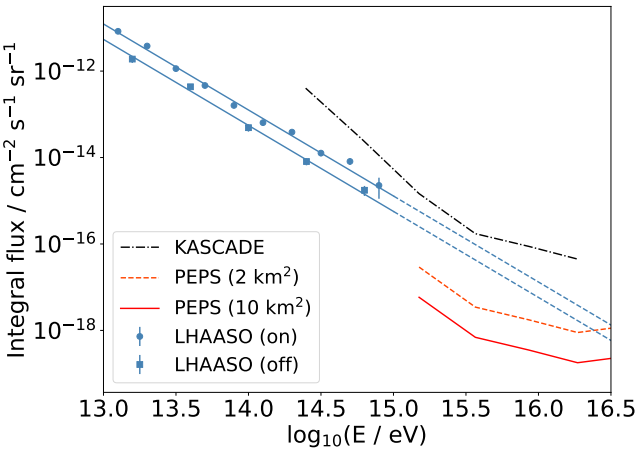

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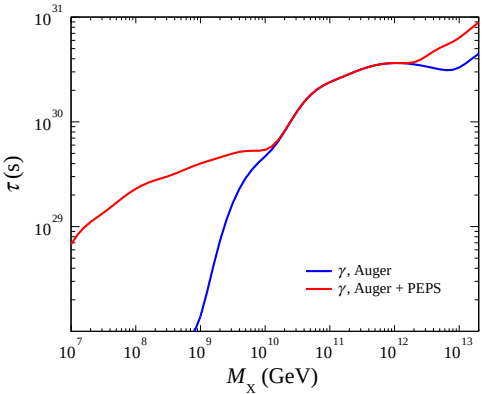
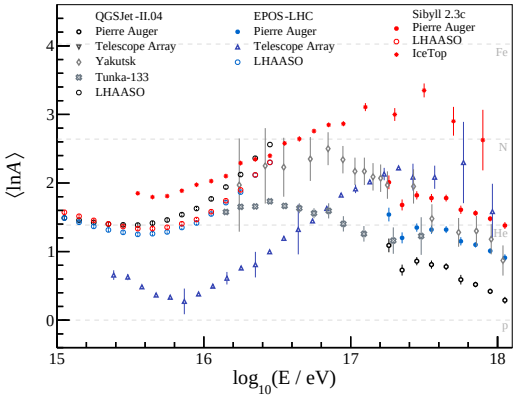
An extra component in the diffuse flux?

Super-heavy dark matter and charged cosmic rays



from O. Deligny

Probes of meta-stable super-heavy dark matter
Models with the SHDM decaying into low-multiplicity (e.g. sterile neutrinos, spin 3/2 particles)



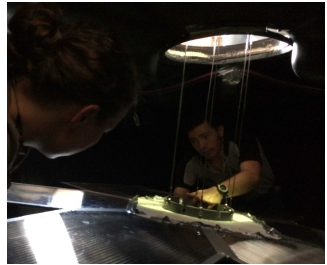
Extend down in energy the Auger measurements (allows for a cross-calibration between fluorescence and surface detectors)

Detector design and construction

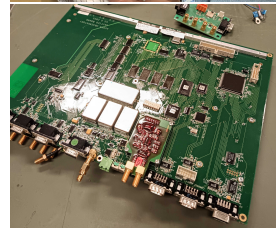
Base the design on robust segmented detectors, leveraging previous expertise and similarities to SWGO
(2 detectors operating since 2014)

Use decommissioned components for non-critical parts
(Pierre Auger Observatory unified boards and solar panels)

Build 3 prototypes in 2025/2026
(testing components and adapting electronics in Brussels)



(2014)



(2024)

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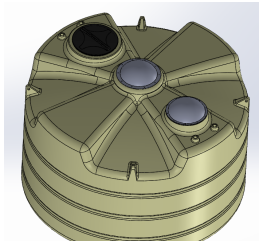
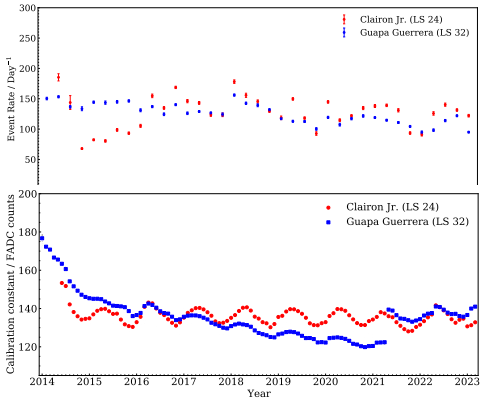


drawings by L. Mendez

(2024)

Stability and calibration of the detector



Use existing infrastructure of the Auger Observatory for assembling, water purification, and deployment

Optimisation of the PEPS geometry (reduce the diameter from 3.6 m to 3 m)

PEPS can be fully operational in 2.5 years

A.Parenti, B.Flaggs, et al, POS(ICRC2025)354

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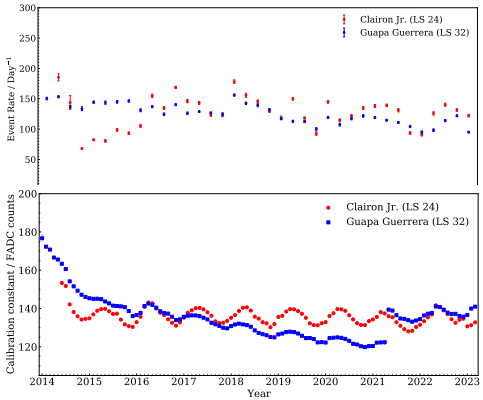

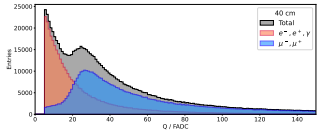

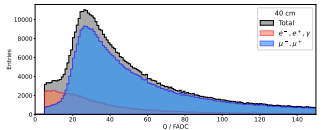

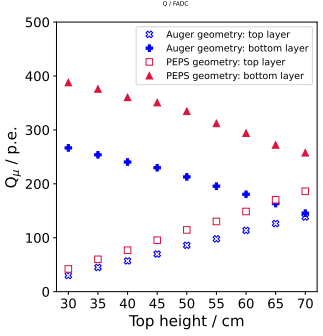

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Probing Extreme PeVatron Sources (PEPS)

→ The worlds largest observatory for gamma-rays in the energy range 1-50 PeV

→ First observation of the most energetic gamma-rays in the Milky Way Galaxy as seen from the Southern sky

→ PEPS 2-km^2: A pioneering first step towards a future 10-km^2 array