Multimessenger studies at the Pierre Auger Observatory

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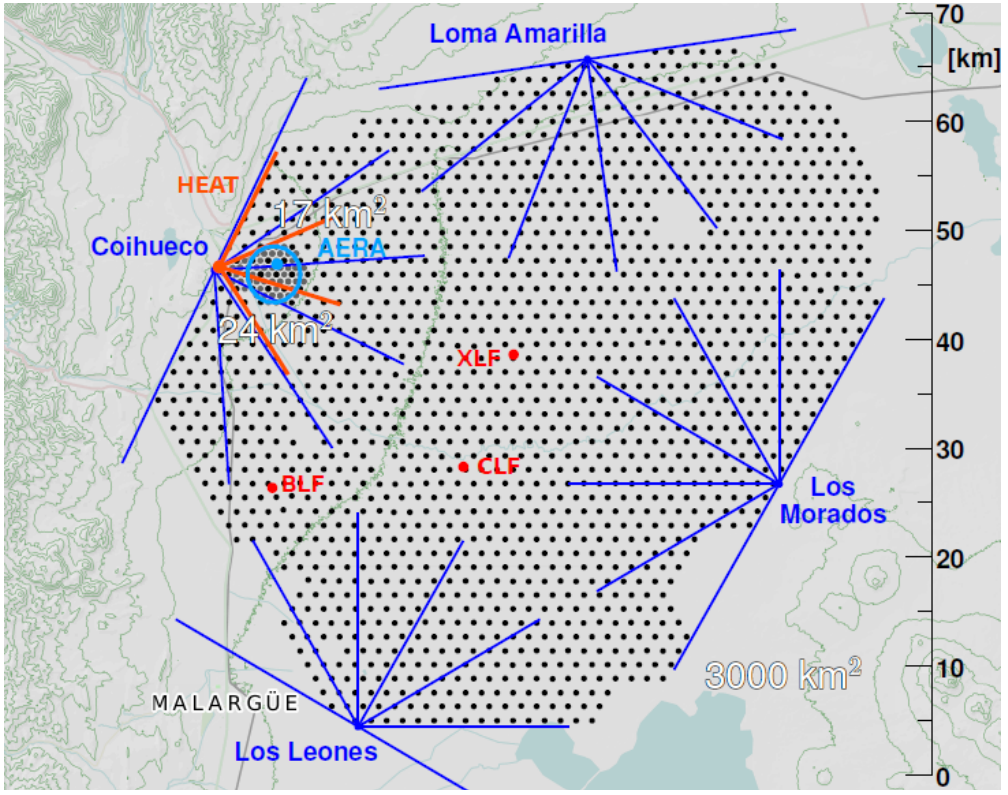
The Pierre Auger Observatory

Surface Detector (SD):
– 1600 Water Cerenkov Detectors at 1.5 km (~3000 km^2) + 31 stations at 0.75 km
– measure particle density at the ground

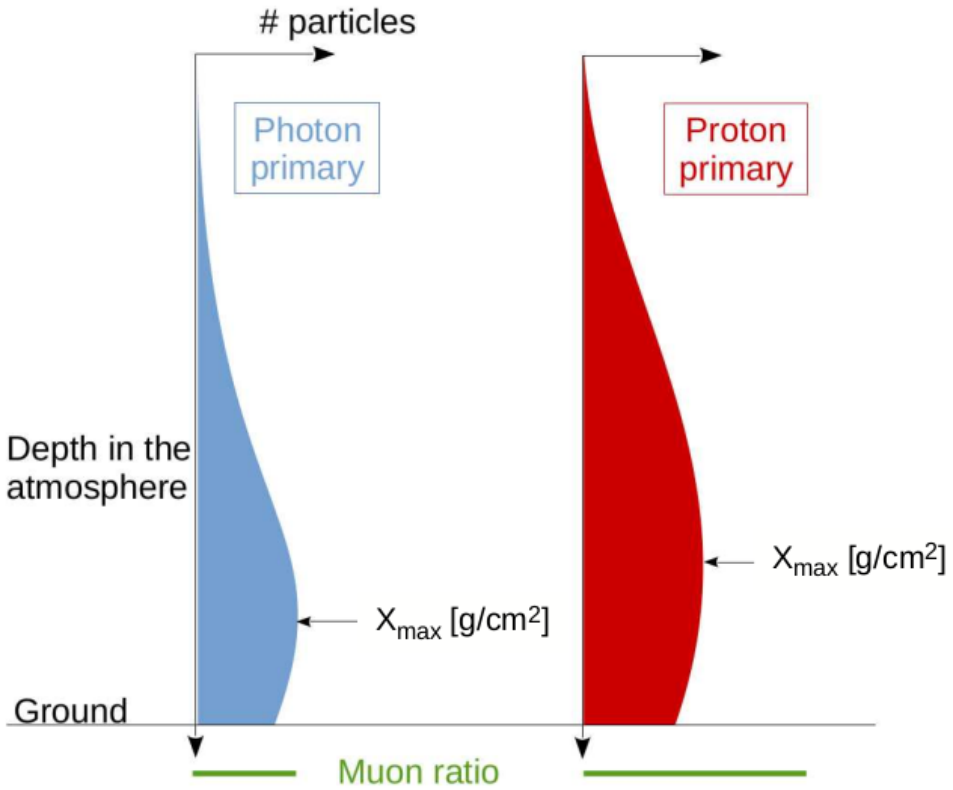
Fluorescence Detector (FD):
– 24 telescopes in 4 sites (FoV 1° - 30°) + 3 high elevation telescopes (FoV 30° - 60°)
– longitudinal profile with a calorimetric measurement

Precise measurement using **hybrid (SD+FD)** technique

Auger Upgrade adding new detectors (SSD, Radio antennas, Underground Muon Detectors) and faster electronics to increase our sensitivity



UHE Photon induced air showers

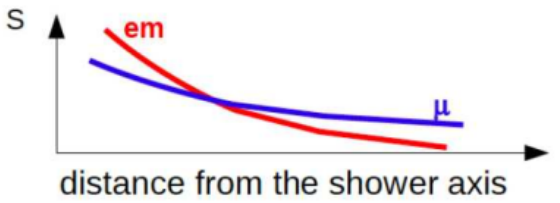


Photons interact deeper in the atmosphere and develop a nearly pure electromagnetic shower (wrt Cosmic Rays)

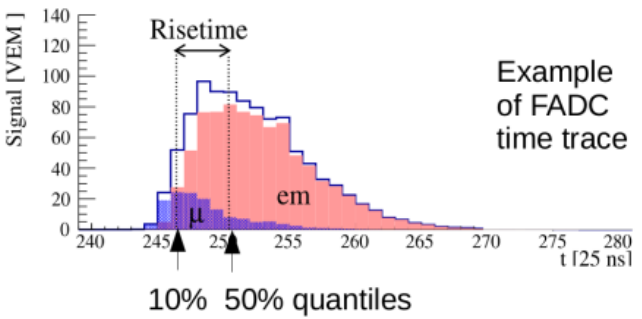
→ higher X_{max}

→ steeper LDF

→ smaller footprint

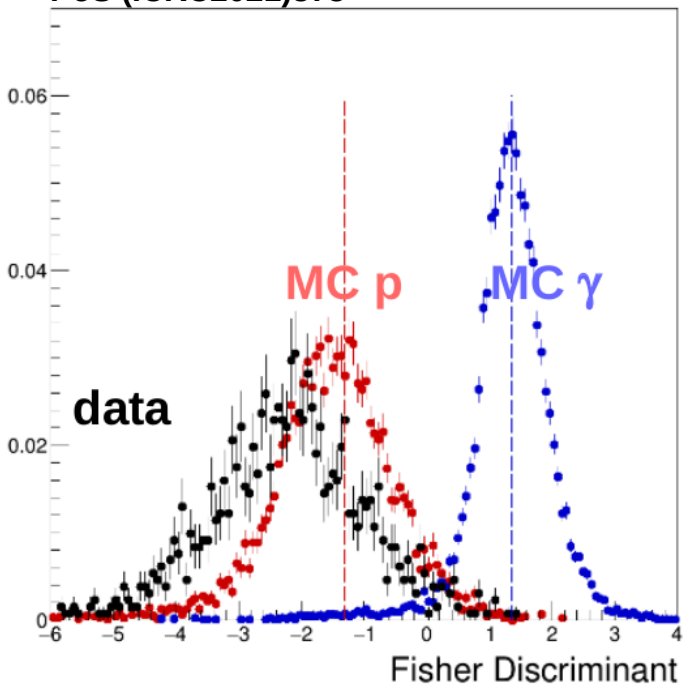


→ larger signal



Hybrid and SD data selection

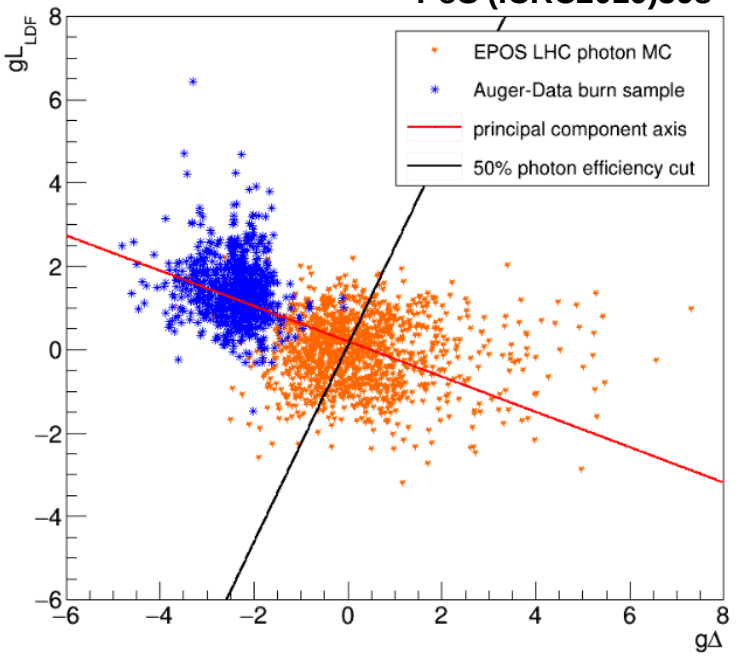
PoS (ICRC2021)373



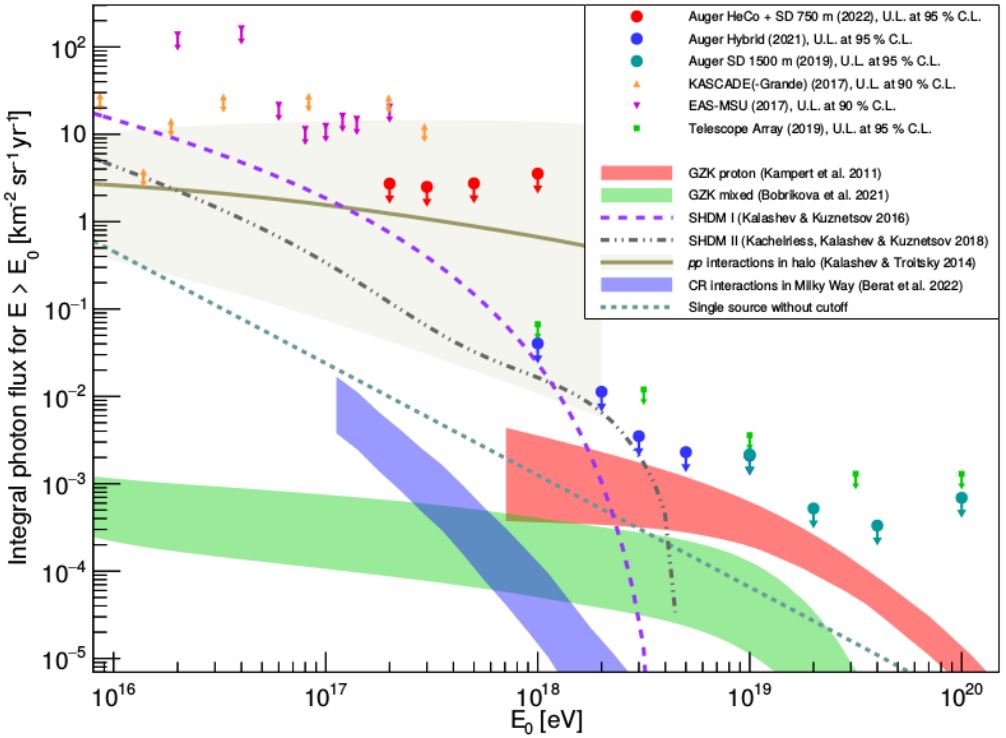
Hybrid selection based on Fisher response to X_{max} and F_{μ} (muon content of the shower)

SD selection based on PCA
Deviation from <LDF> vs <rise-time> using 5% of data and cutting with 50% photon efficiency

PoS (ICRC2019)398



Photons upper limits



Ap. J. 933 (2022)125 low energy extension
PoS(ICRC2021)373 Auger hybrid
PoS(ICRC2019)398 Auger SD

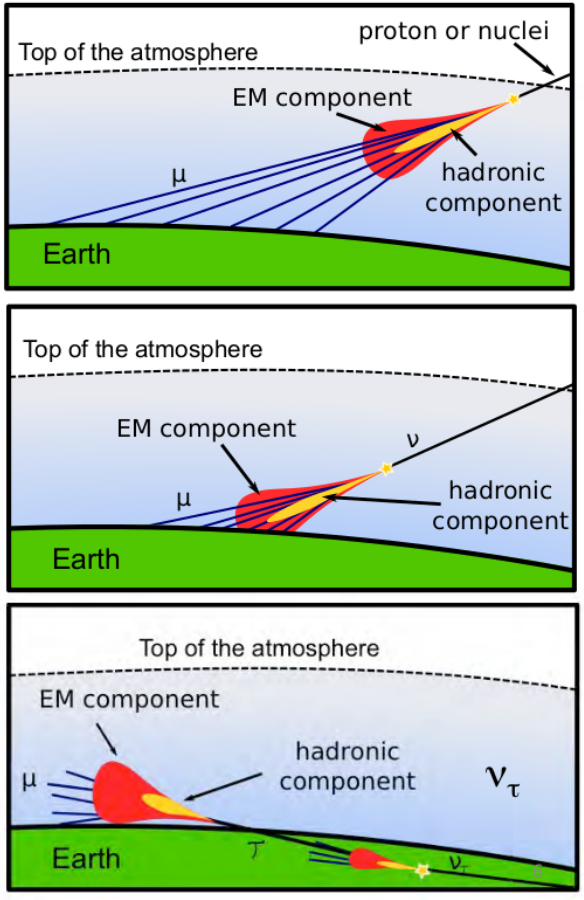
– Disfavouring top-down models
– Constraining mass and lifetime of dark matter particles
– Constraining cosmogenic fluxes (need more exposure)
– With Auger Phase II more information to better discriminate the primary particle

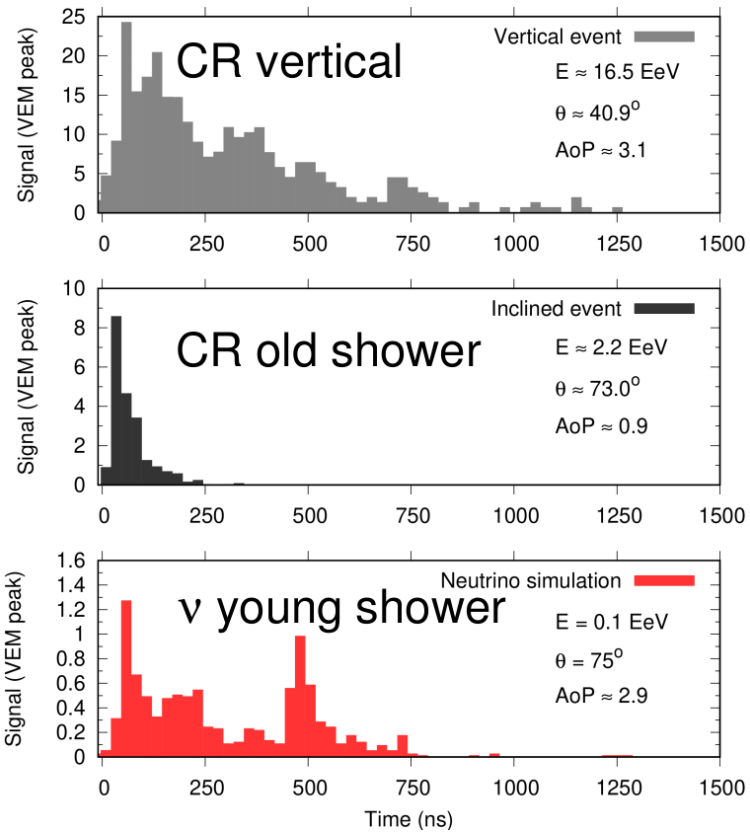
Inclined shower and UHE Neutrino signature

The EM component in inclined **CR** showers (zenith > 60°) almost completely absorbed by the atmosphere.

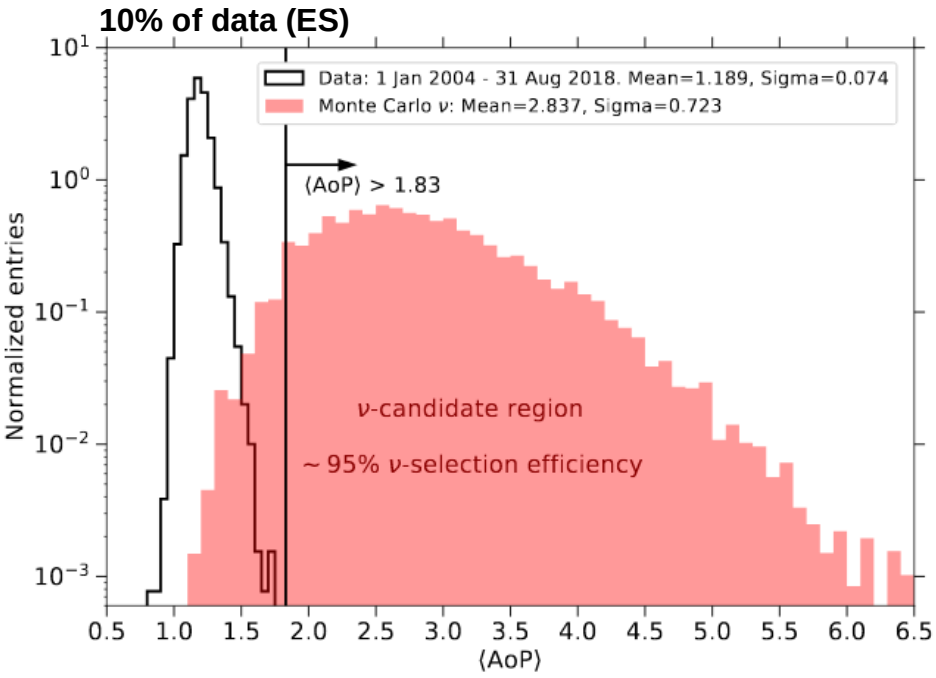
On the other hand, neutrinos have younger shower
→ broader signal in inclined event can be a neutrino signature

3 main channels:
– **Down-Going Low** (60°-75°)
– **Down-Going High** (75°-90°)
– **Earth-Skimming** (90°-95°)

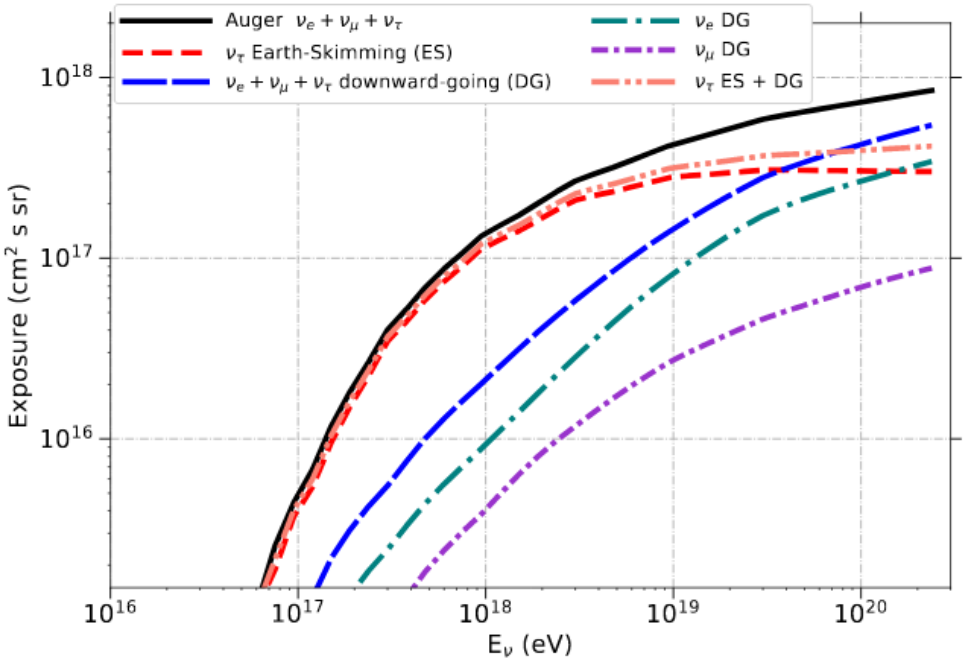




UHE Neutrino data selection



Pierre Auger Coll., JCAP 10 (2019) 022



– **Area over Peak** is the sensitive variable
– Cut tuned on all the different channels
– Expected <1 bkg event in 50 years

– Exposure dominated by the ES channel
– DG channels become relevant at higher energies (ES neutrinos absorbed in Earth)

Diffuse flux limits on UHE Neutrino

Pierre Auger Coll., JCAP 10 (2019) 022

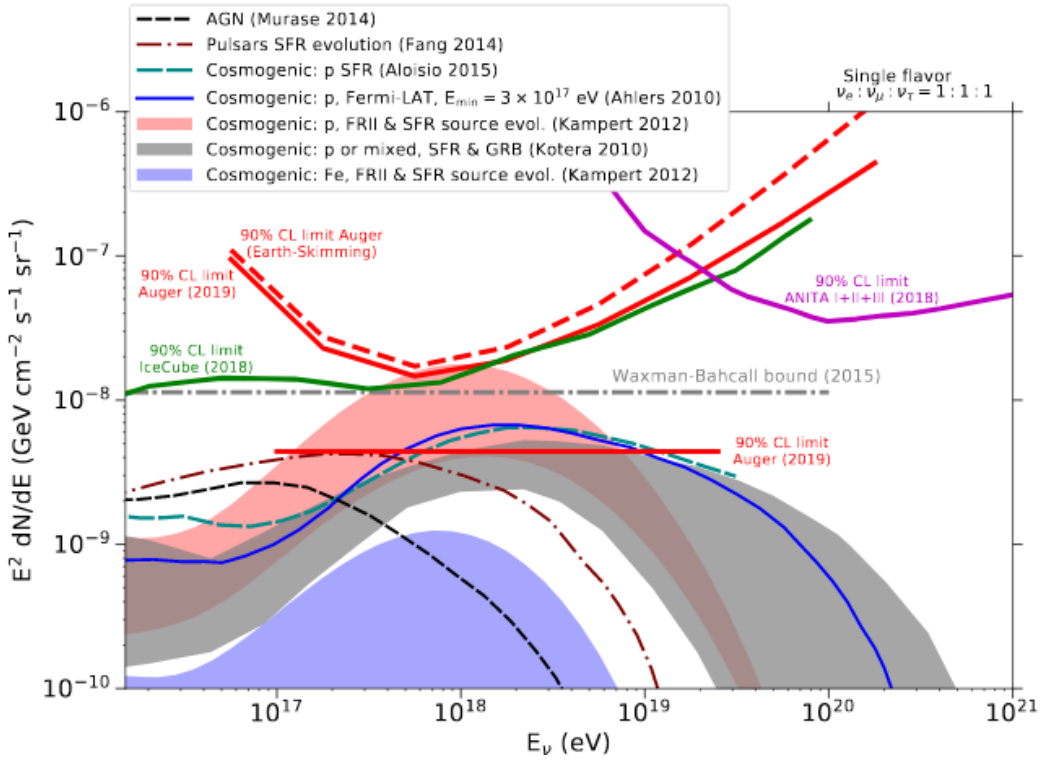
– **NO candidates found**

– Maximum sensitivity at ~ **1 EeV**

– Integral upper limits constrains different models.

– Expected up to 6 events in case of pure proton composition, 2 in case of p or mixed, 0.4 in case of pure iron

– Our increase in exposure allow us to disfavour pure proton models



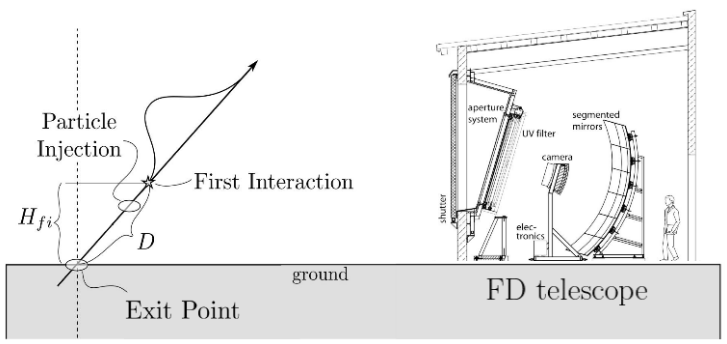
Search for FD up-going air showers

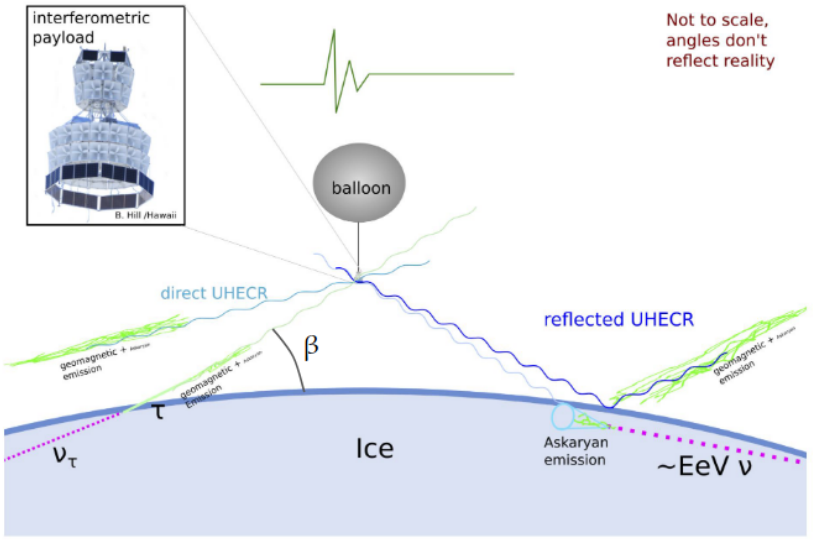
Two “anomalous” events detected by **ANITA** with non-inverted polarity
→ E ~ 0,2 EeV, exit angle ~ 30°

Fervent debate about the interpretation

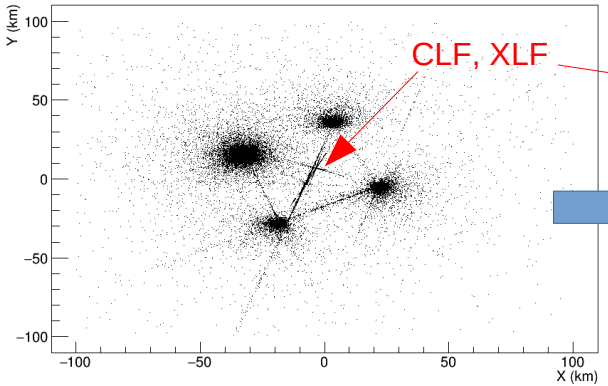
Highly inclined events cannot be observed with SD
→ Dedicated search using 14 years of FD data

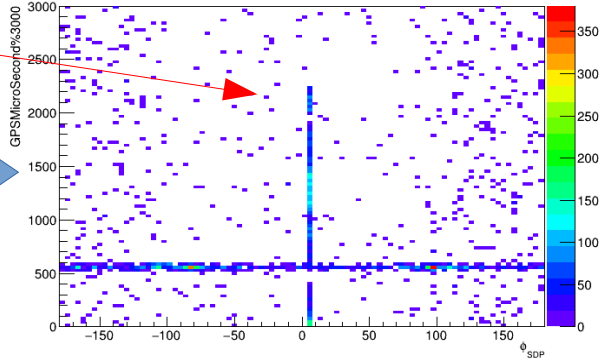
FD sensitivity depends on E and H_{fi} of the primary particle

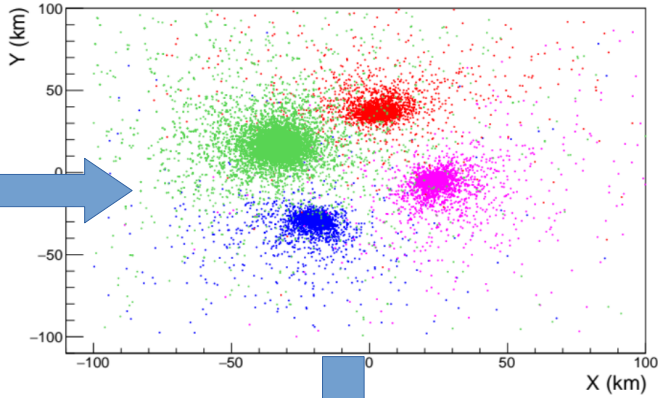


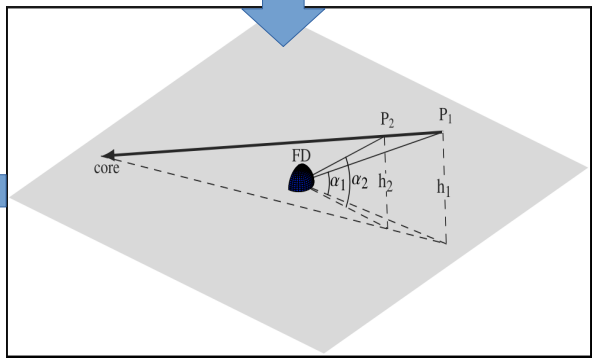


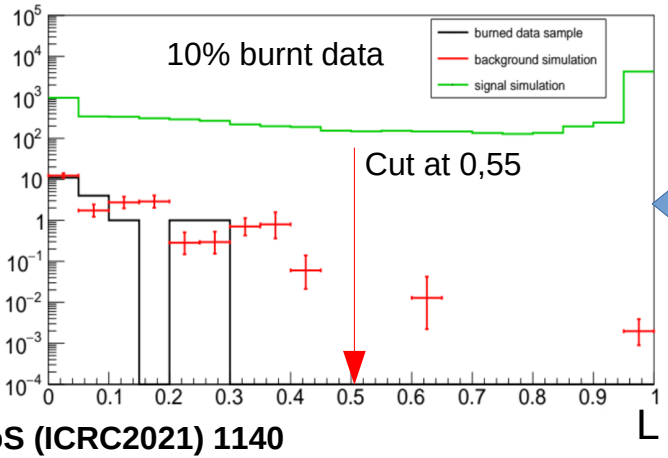
Data selection











Expected background events in full data sample
0.45 ± 0.18

PoS (ICRC2021) 1140

Differential exposure and signal expectation

Double differential exposure in H_{fi} vs E_{cal}

1 event found after the unblinding in line with the expected background

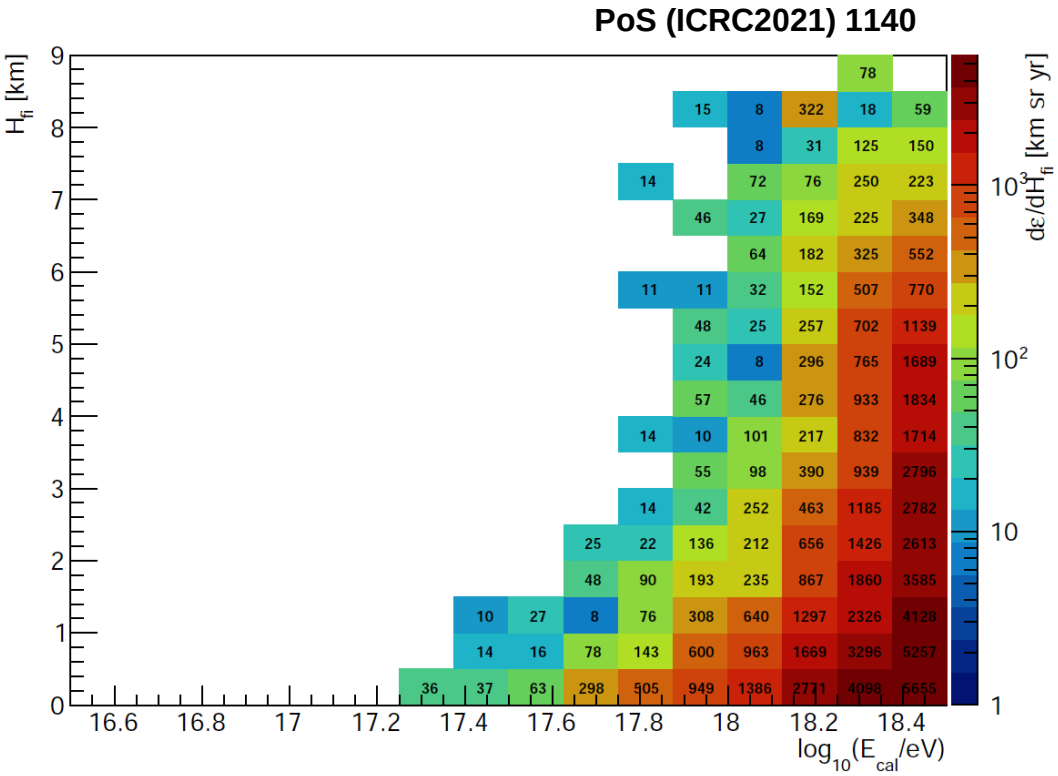
Integral upper limit:

$$F^{95\%}_{\gamma=1} = 3.6 \cdot 10^{-20} \mathrm{cm}^{-2}\mathrm{sr}^{-1}\mathrm{s}^{-1}$$

$$F^{95\%}_{\gamma=2} = 8.5 \cdot 10^{-20} \mathrm{cm}^{-2}\mathrm{sr}^{-1}\mathrm{s}^{-1}$$

Ongoing collaboration with ANITA to obtain their exposure and compare the results

Also studying other interesting scenario such as a tau-initiated showers (**PoS (ICRC2021) 1145**)



Conclusion

– The Pierre Auger Observatory gives its contribution to the International MM Community providing information at the highest energy

– High sensitivity for photons and neutrinos
  → the non-observation provides important results, setting stringent limits and constraining exotic scenarios

– Also different follow-up analysis
  → GW170817 (**ApJL 850 L35 2017**)
  → Neutrino and Photon GW stacked (**PoS (ICRC2021) 968** and **973**)
  → TXS0506+056 (**ApJ 902:105 (2020)**)
  and joint searches
  → ANTICATA (**ApJ 934:164 (2022)**)

– The upgrade will provide more information allowing us to increase our sensitivity and background rejection

Thank you for your attention!