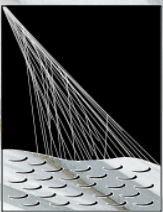


Probing the Flux of Ultra-High-Energy Neutral Particles at the Pierre Auger Observatory



Fiona Ellwanger for the Pierre Auger Collaboration – (spokespersons@auger.org)



PIERRE
AUGER
OBSERVATORY

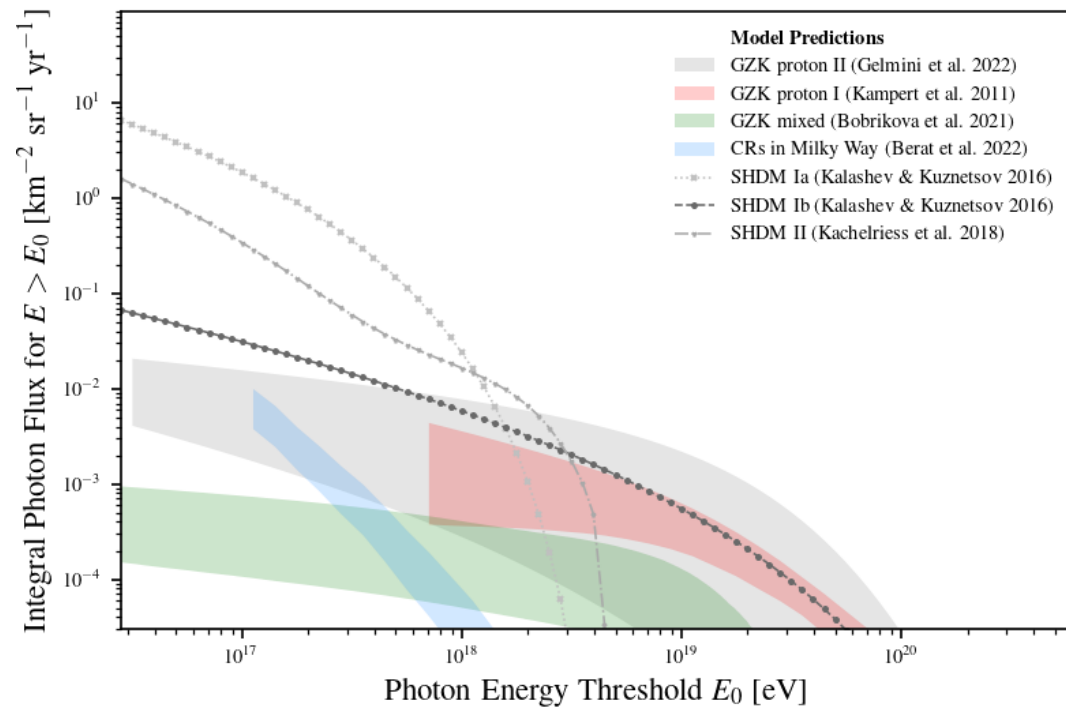
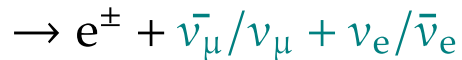
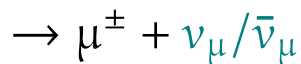
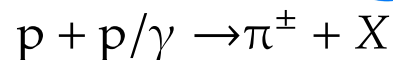
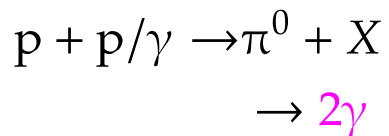
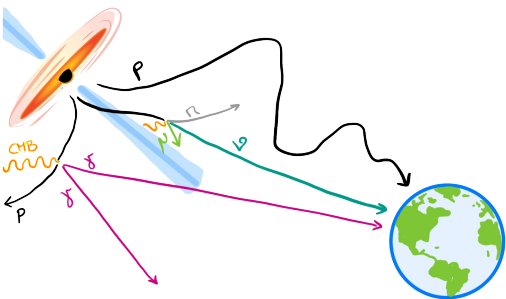
Production of Ultra-High Energy Photons/Neutrinos

→ *Astrophysical*: sources of cosmic rays

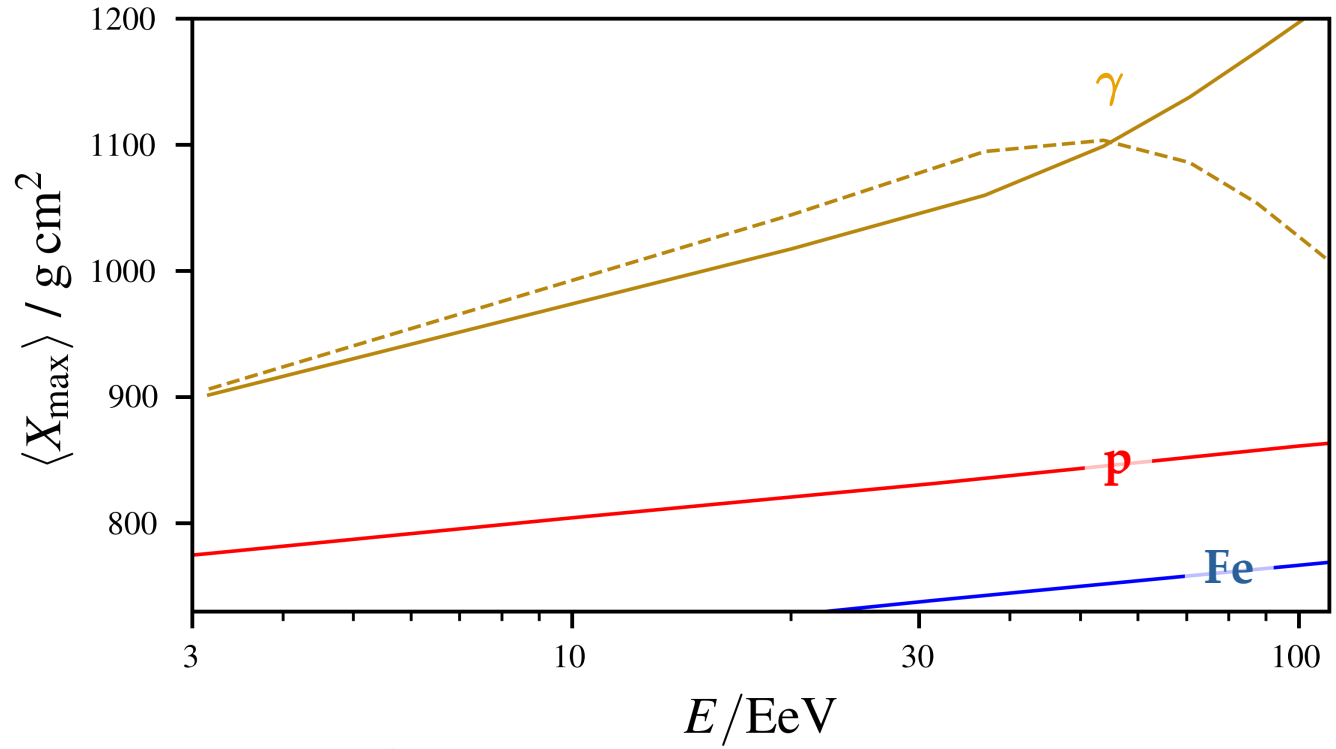
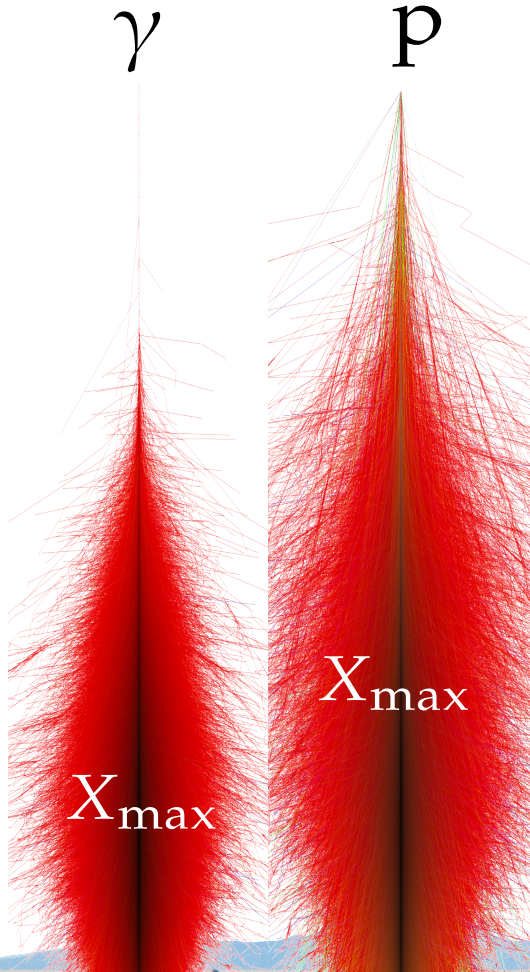
also produce γ and ν

→ *Cosmogenic*:

- interaction with CMB (GZK)
- interaction with matter (e.g. in galactic disk)
- decay of super-heavy dark matter



Photon induced air showers

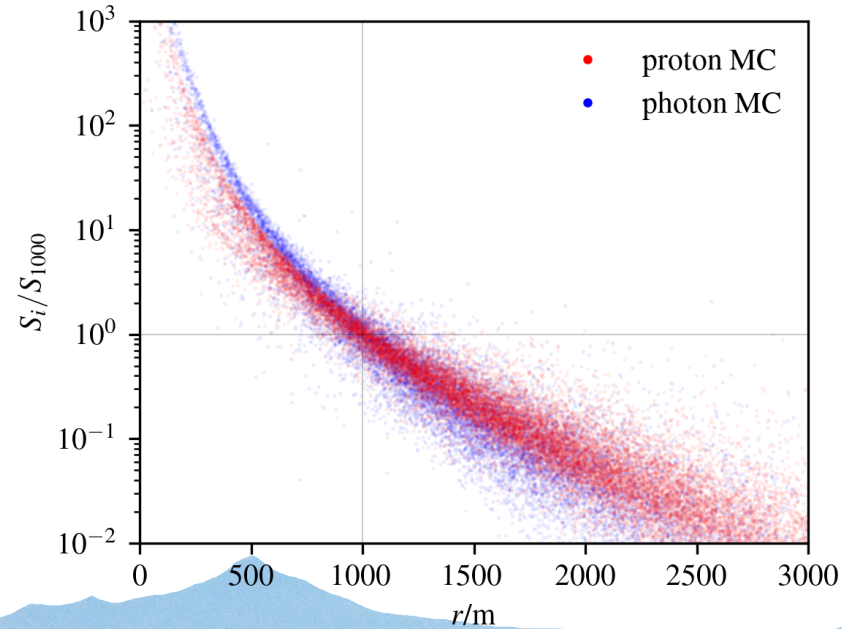


Photon induced air showers

γ

p

- deeper maximum of the shower $X_{\max}$
- steeper lateral distribution of particles

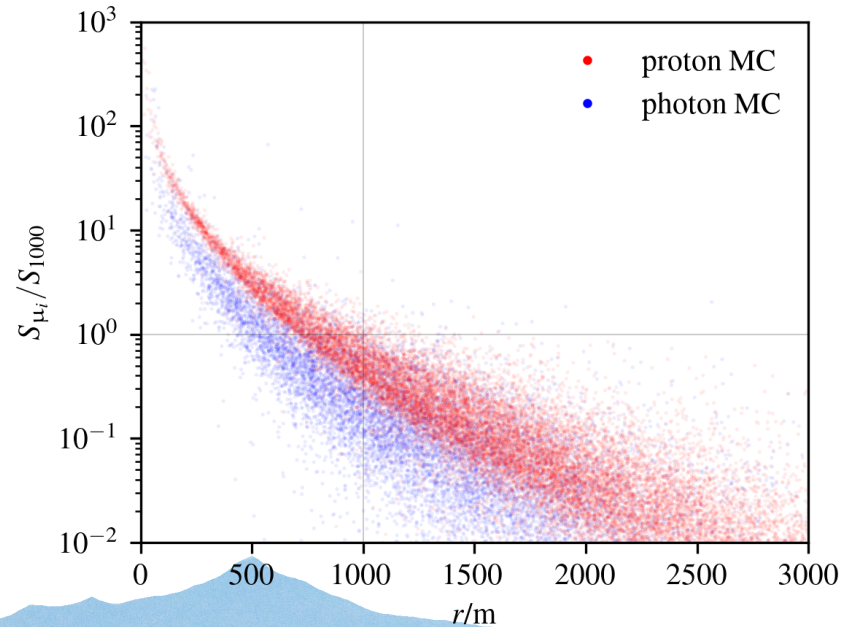


Photon induced air showers

γ

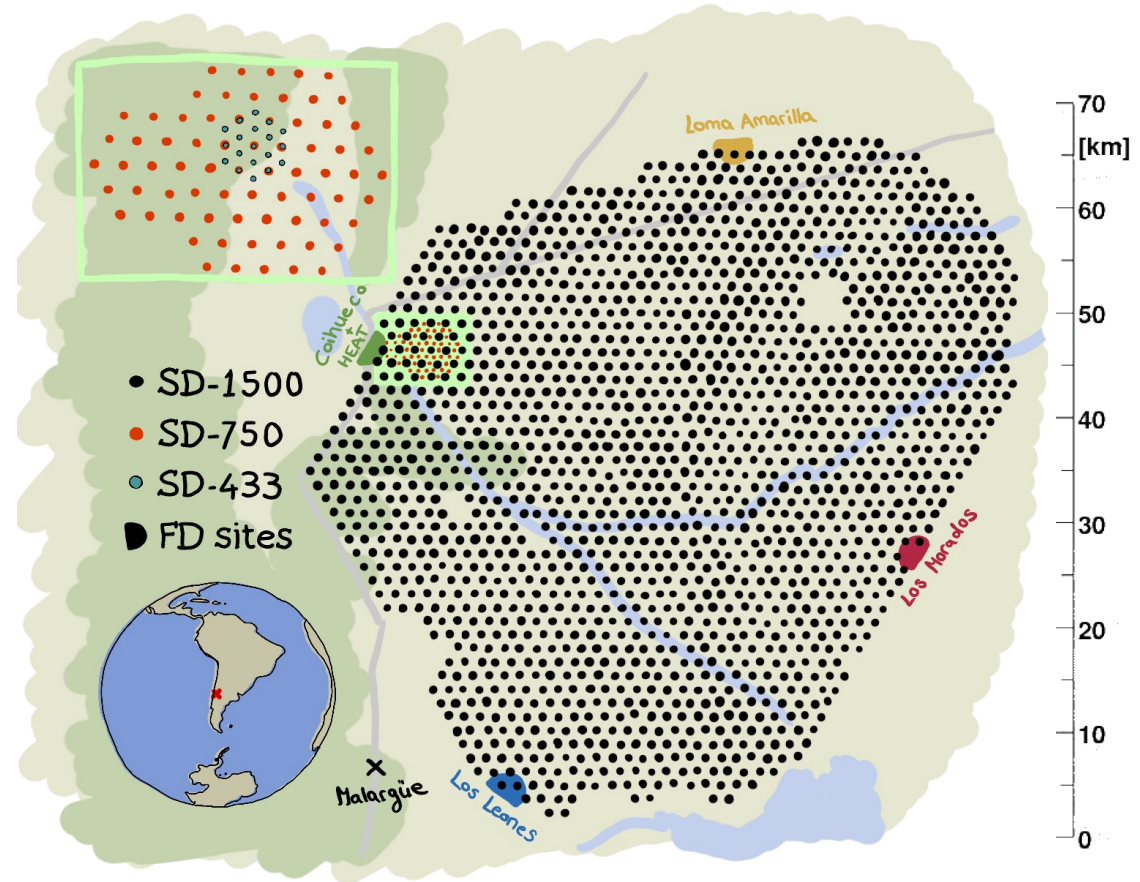
p

- deeper maximum of the shower $X_{\max}$
- steeper lateral distribution of particles
- reduced hadronic component
- suppressed muonic component



The Pierre Auger Observatory

- 1400m altitude
- 3000 km²
- Designed to detect secondary particles of extensive air showers
- Hybrid detector layout
 - Fluorescence Detector
 - Surface Detector



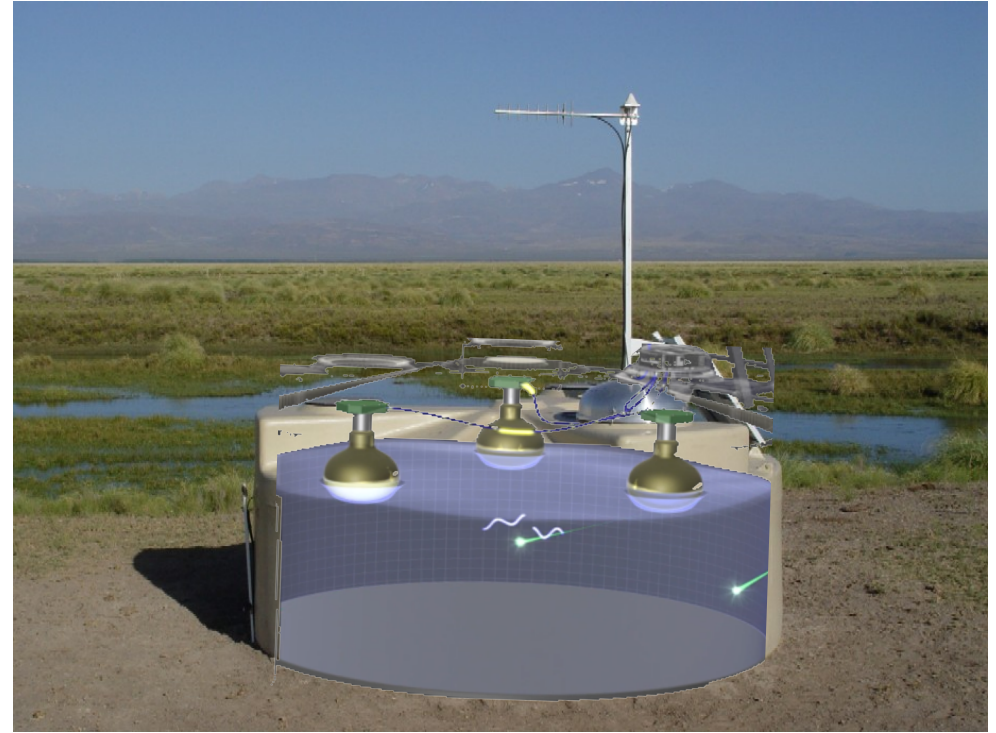
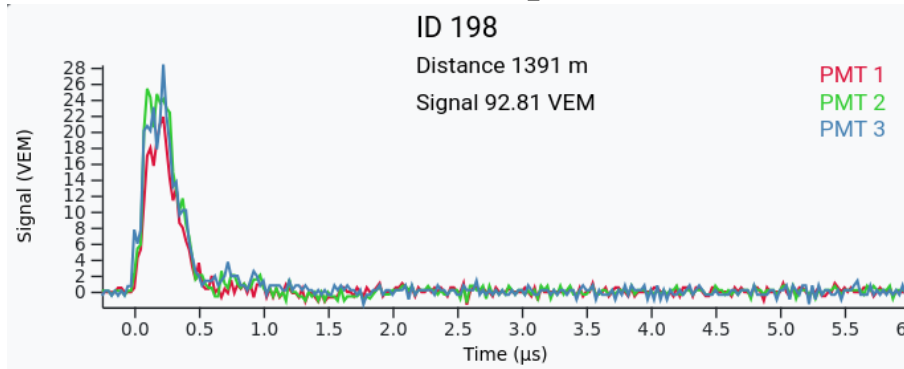
The Surface Detector (SD)

- >1600 water-Cherenkov detector stations
- triangular grid
- 3 arrays with different densities
 - 1500 m spacing
 - 750 m spacing
 - 433 m spacing
- 100% duty-cycle
- Calibrated with atmospheric muons



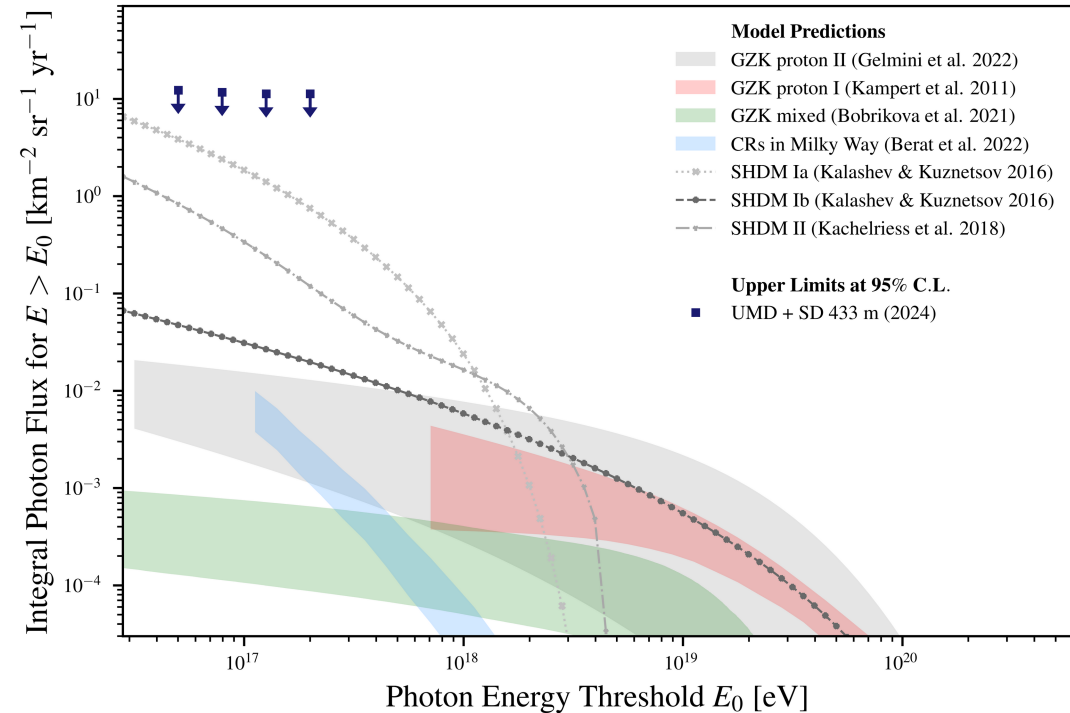
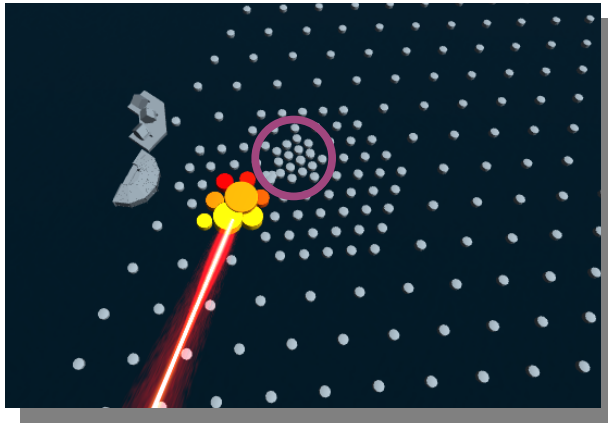
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Diffuse flux of photons with energies above tens of PeV

→ Estimate on muon density, ρ_μ , from
underground muon detectors (UMD)

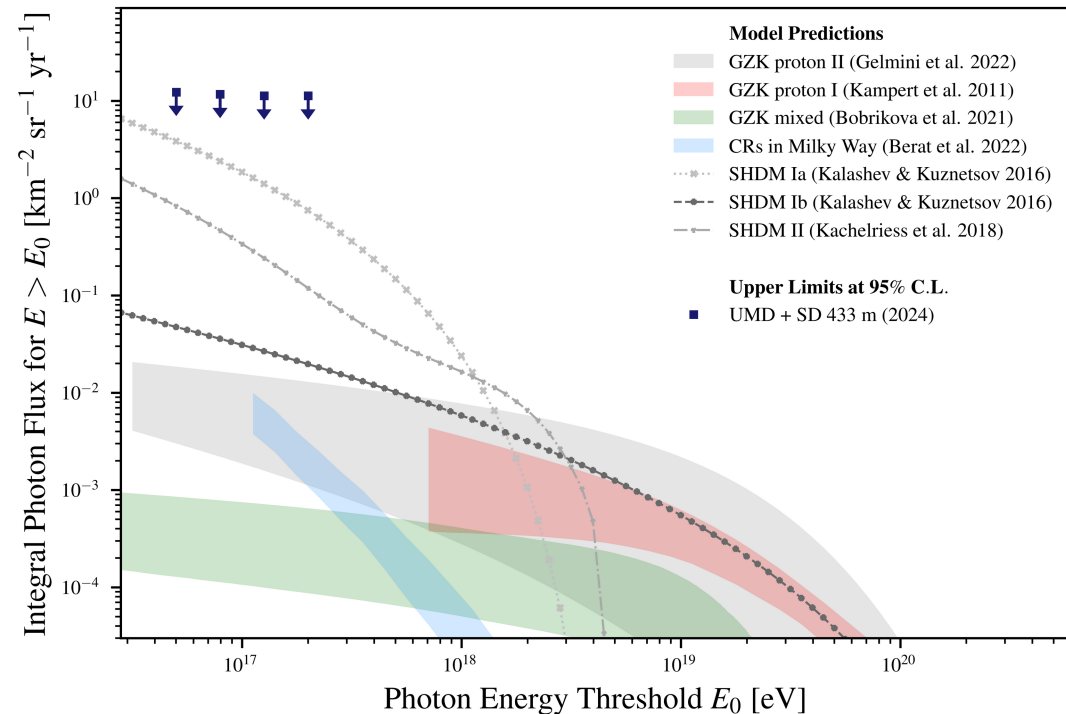
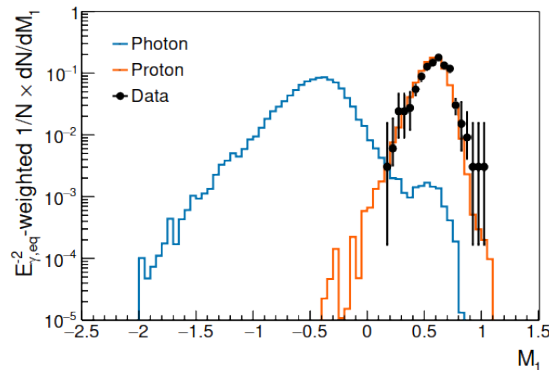


Diffuse flux of photons with energies above tens of PeV

→ Estimate on muon density, ρ_μ , from
underground muon detectors (UMD)

→ No candidate γ found

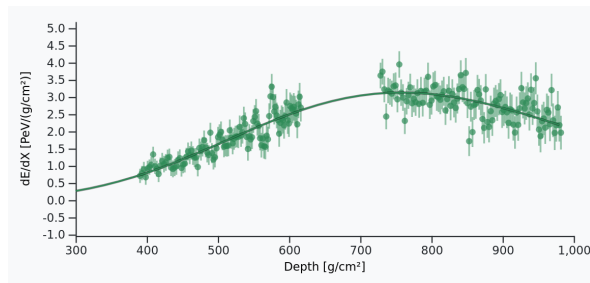
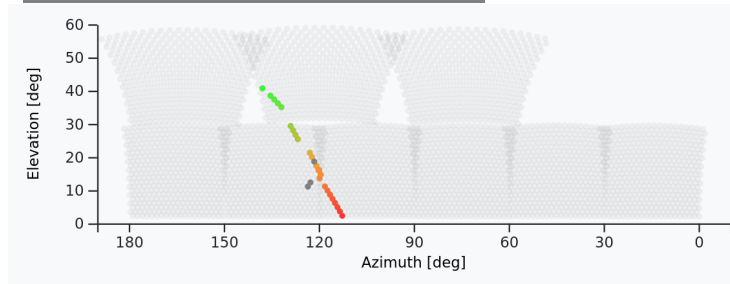
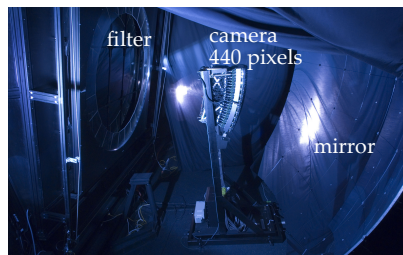
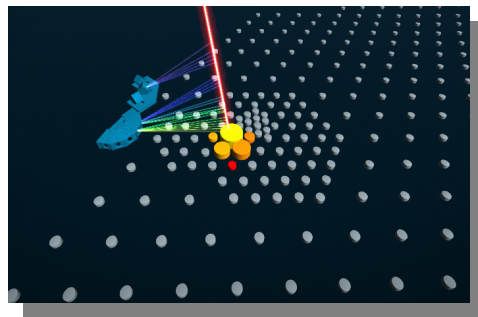
$$M_1 = \lg \left(\sum_i^{\text{stations}} \frac{\rho_\mu(r_i)}{\rho_\mu^{\text{proton}}(r_{\text{ref}})} \left(\frac{r_i}{r_{\text{ref}}} \right) \right)$$



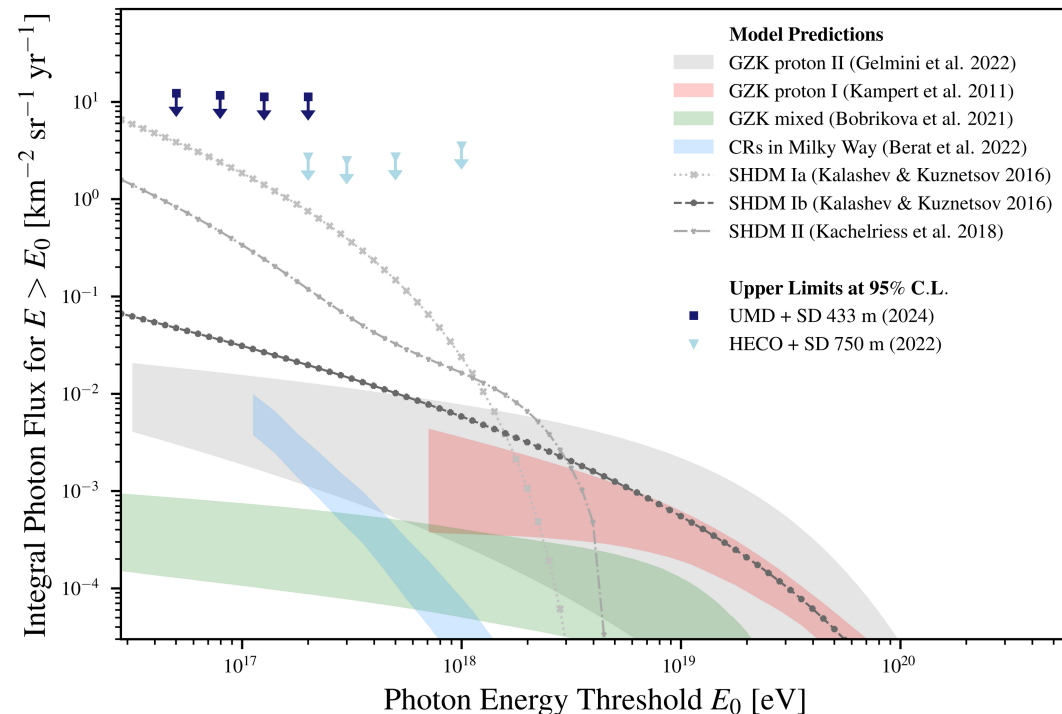
Diffuse flux of photons with energies above 2×10^{17} eV

ApJ 933 (2022) 125

→ hybrid data from the low-energy extensions



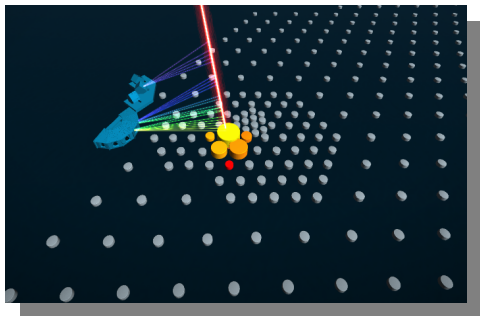
→ X_{max}



Diffuse flux of photons with energies above 2×10^{17} eV

ApJ 933 (2022) 125

→ hybrid data from the low-energy extensions



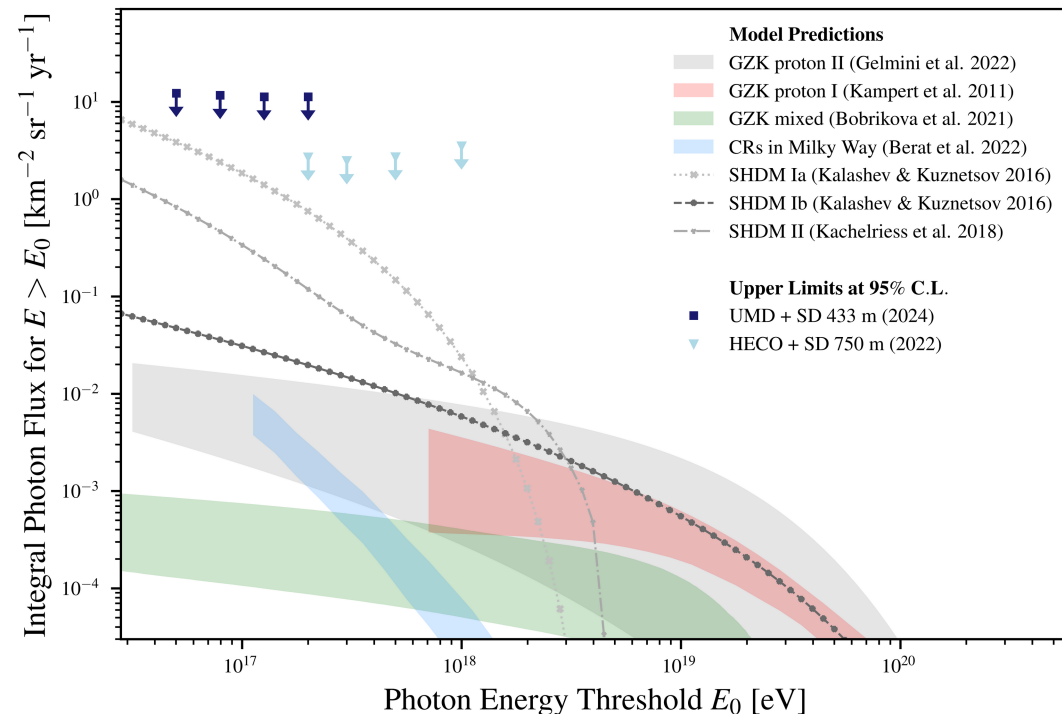
→ BDT analysis

- $X_{\max}$ from FD
- Steepness of the LDF

$$S_4 = \sum_i^{\text{stations}} S_i \left(\frac{r_i}{1000 \text{ m}} \right)^4$$

- Number of stations, N_{stations}

→ No γ candidates found



Diffuse flux of photons with energies above 10^{18} eV

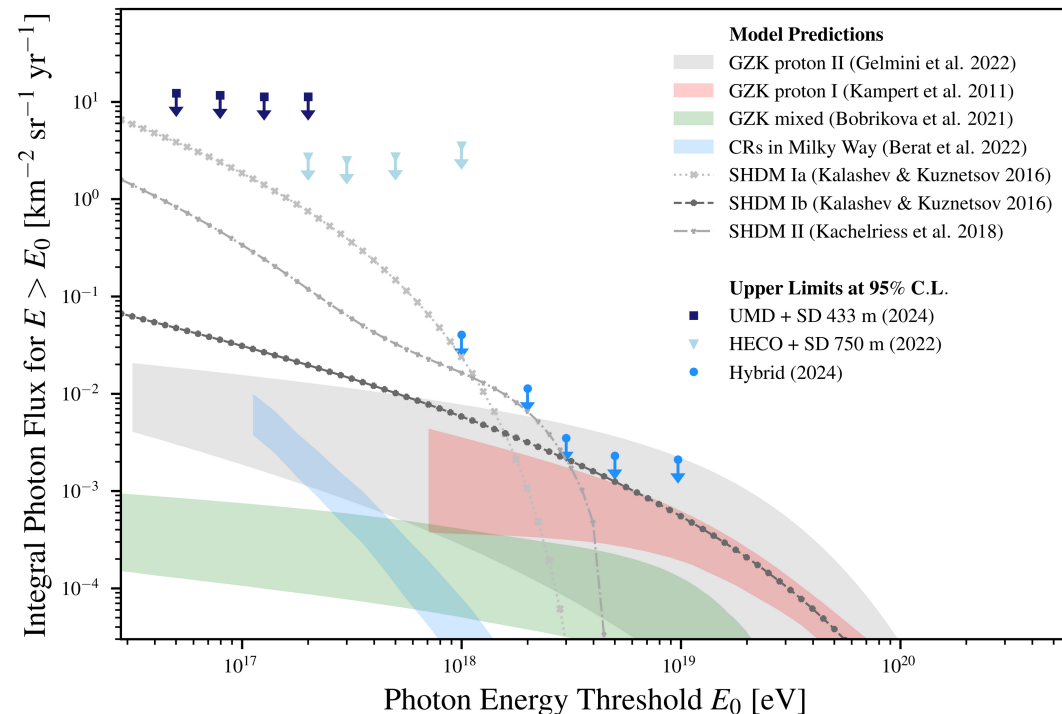
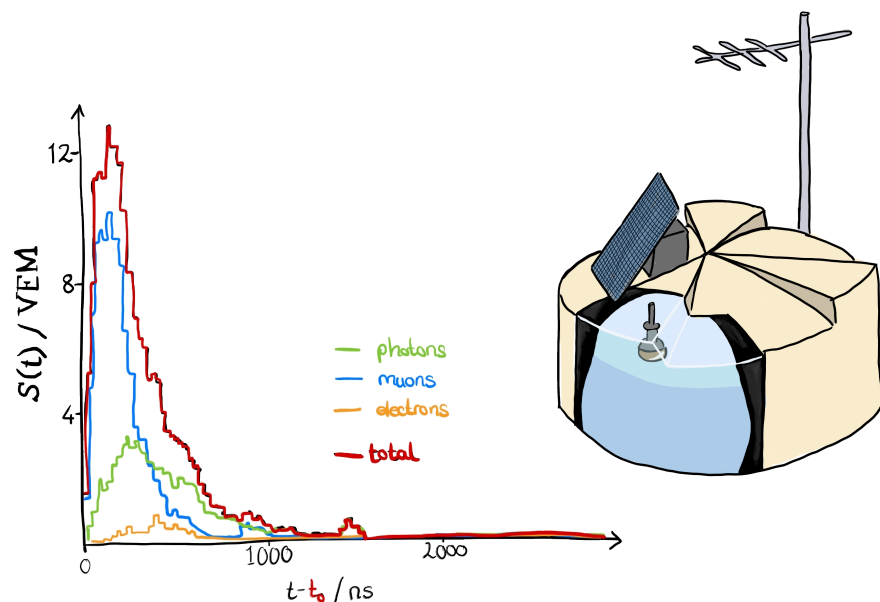
PRD 110 (2024) 062005

→ Hybrid data

→ Fluorescence detector → $E, \mathbf{X}_{\text{max}}, (\theta, \phi)$

→ At least one SD station

→ shower universality model → F_{μ}



Diffuse flux of photons with energies above 10^{18} eV

PRD 110 (2024) 062005

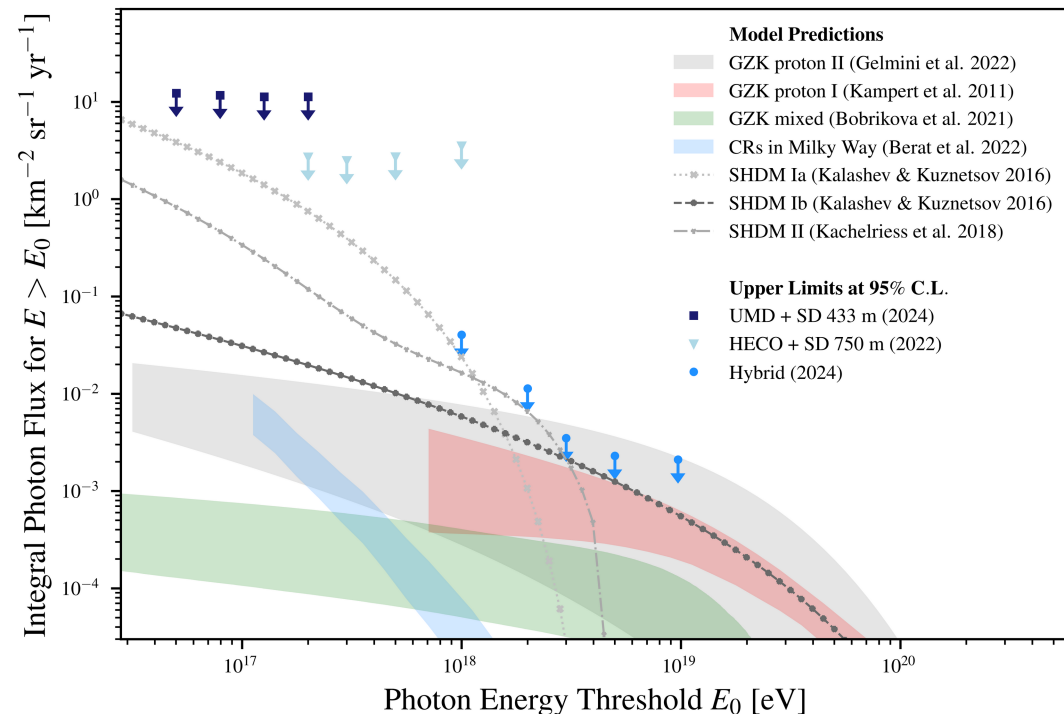
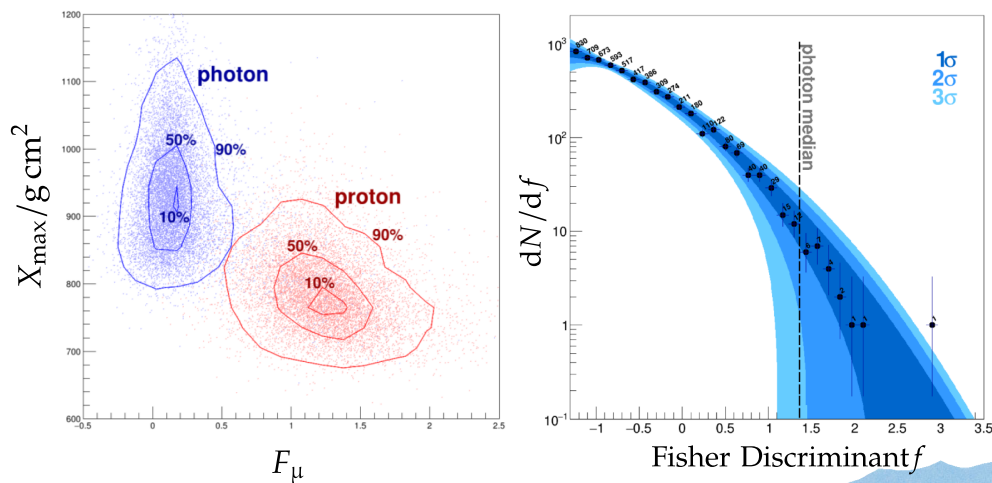
→ Hybrid data

→ Fluorescence detector → $E, \mathbf{X}_{\max}, (\theta, \phi)$

→ At least one SD station

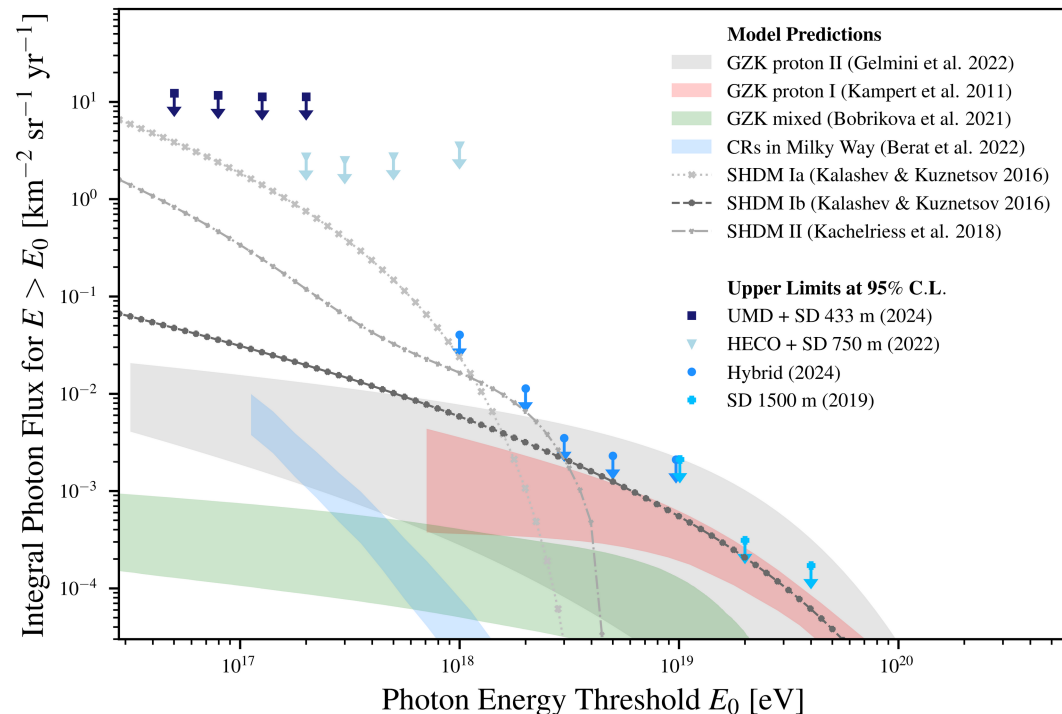
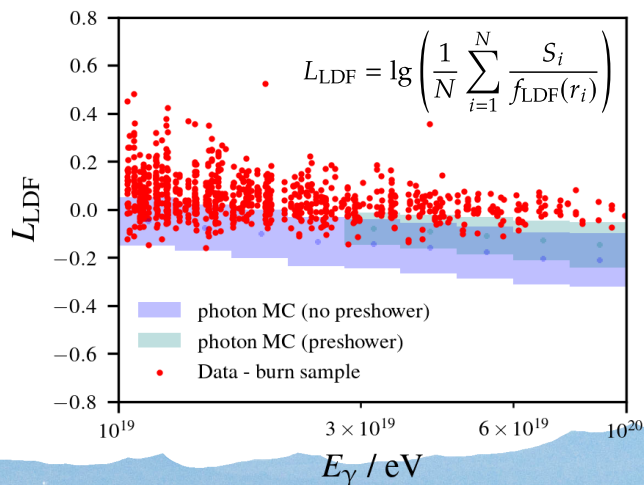
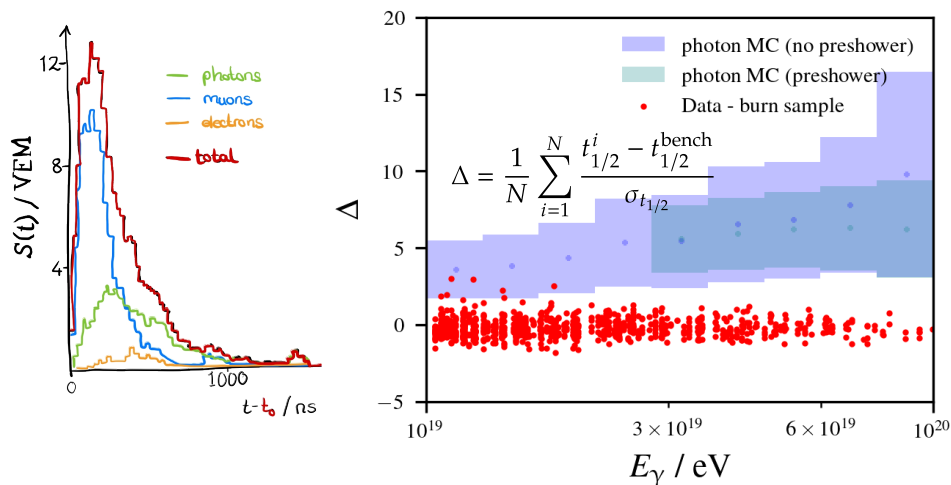
→ shower universality model → F_{μ}

$$F_{\mu} = \frac{S_{\mu}}{S_{\mu}(\text{proton})}.$$

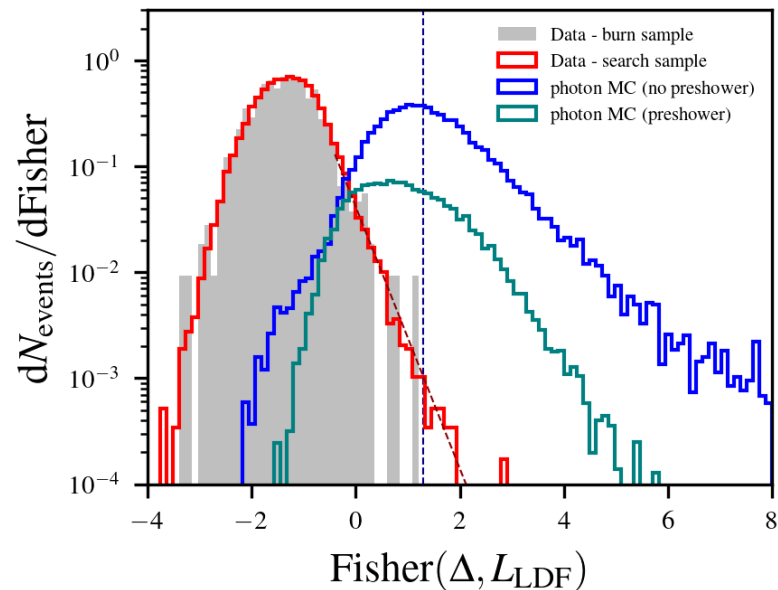


→ 22 candidates, consistent with expected background (30 ± 15)

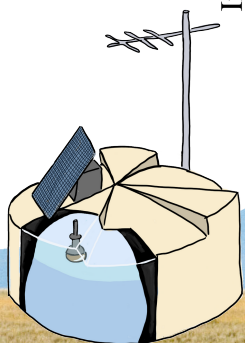
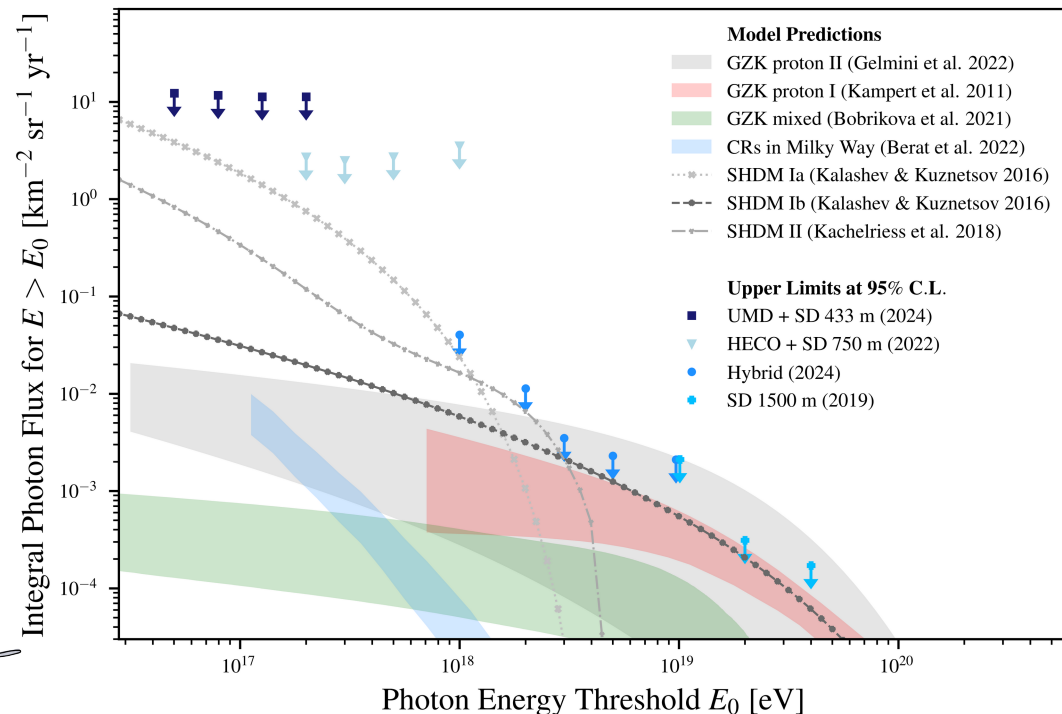
Diffuse flux of photons with energies above 10^{19} eV



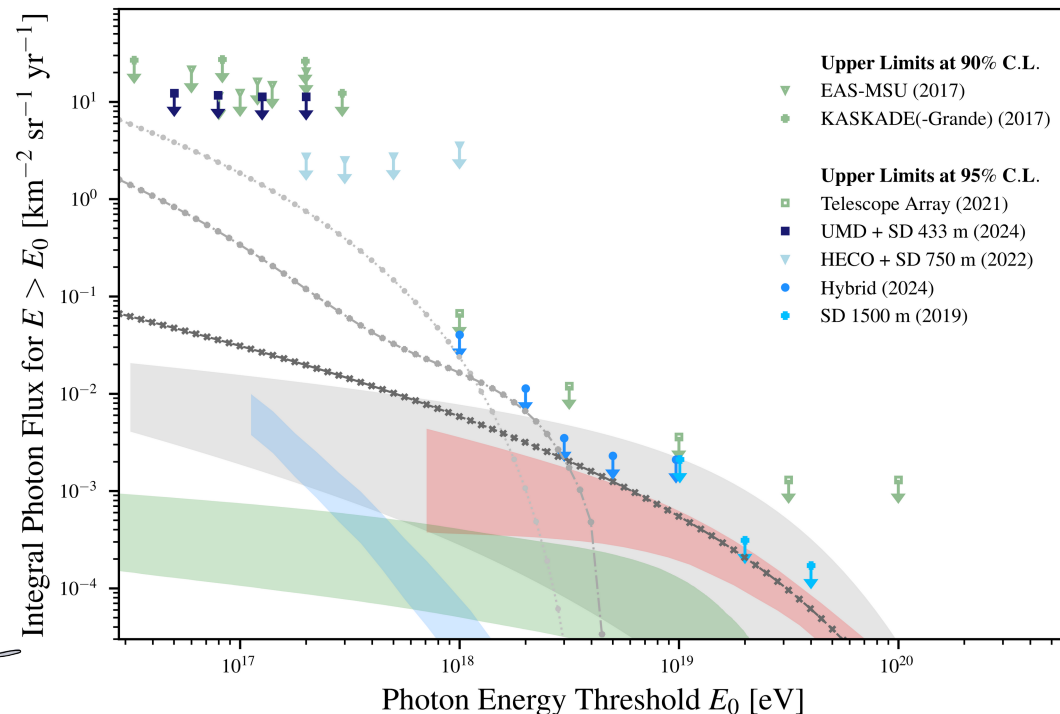
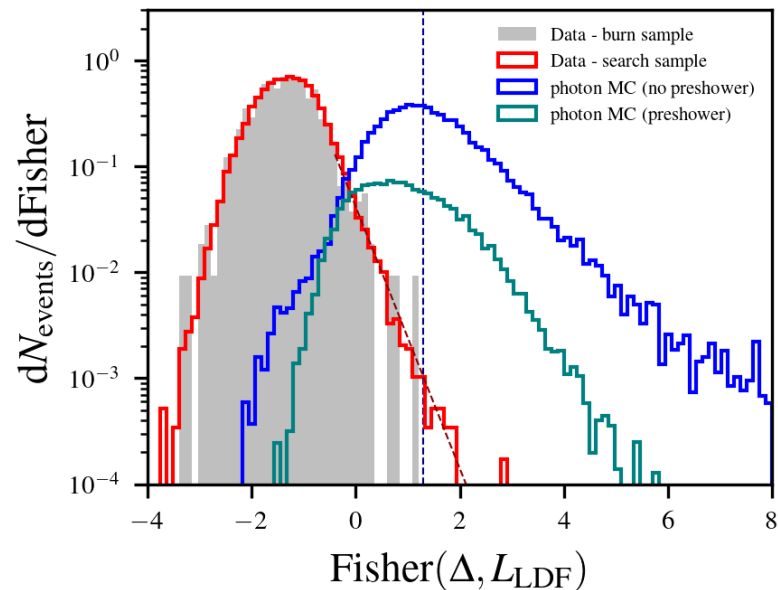
Diffuse flux of photons with energies above 10^{19} eV



→ 16 candidates, consistent with expected background

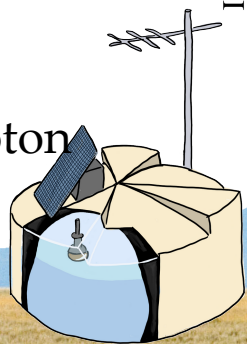


Diffuse flux of photons with energies above 10^{19} eV



→ 16 candidates, consistent with expected background

→ world leading limits on UHE photon flux



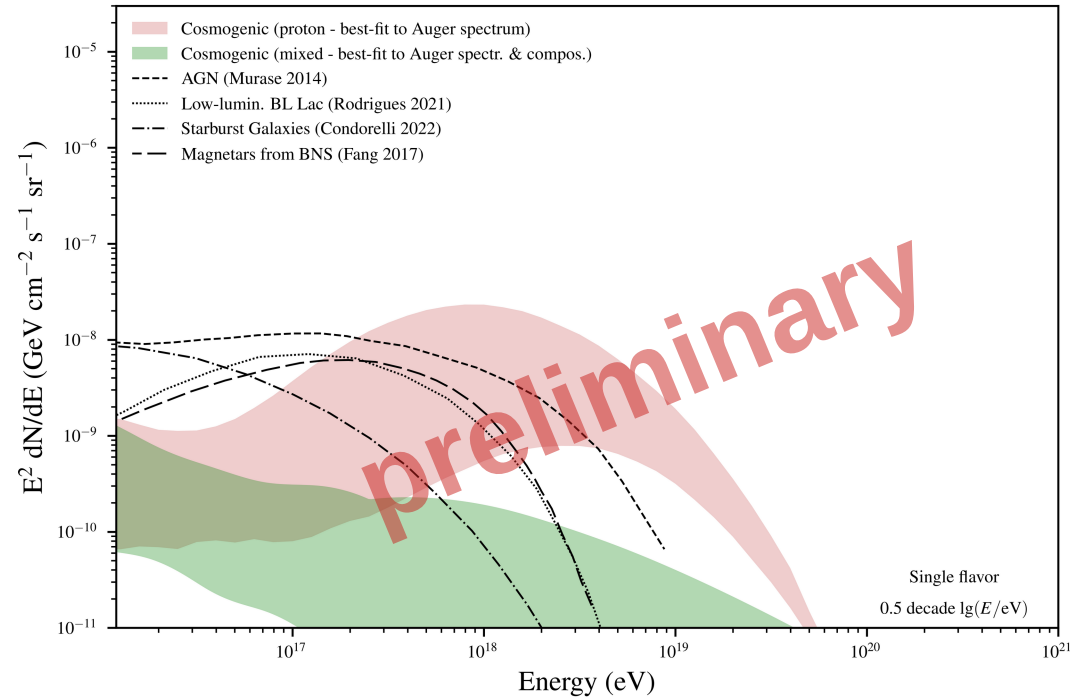
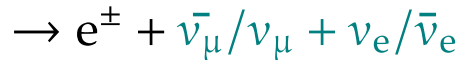
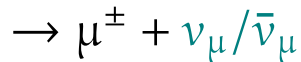
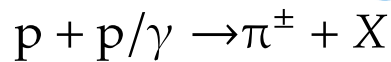
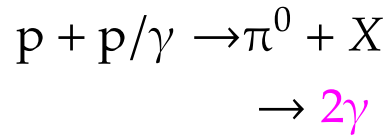
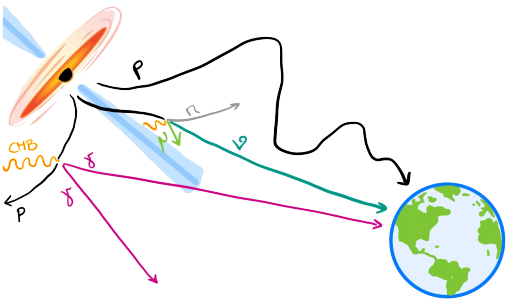
Production of Ultra-High Energy Photons/Neutrinos

→ *Astrophysical*: sources of cosmic rays

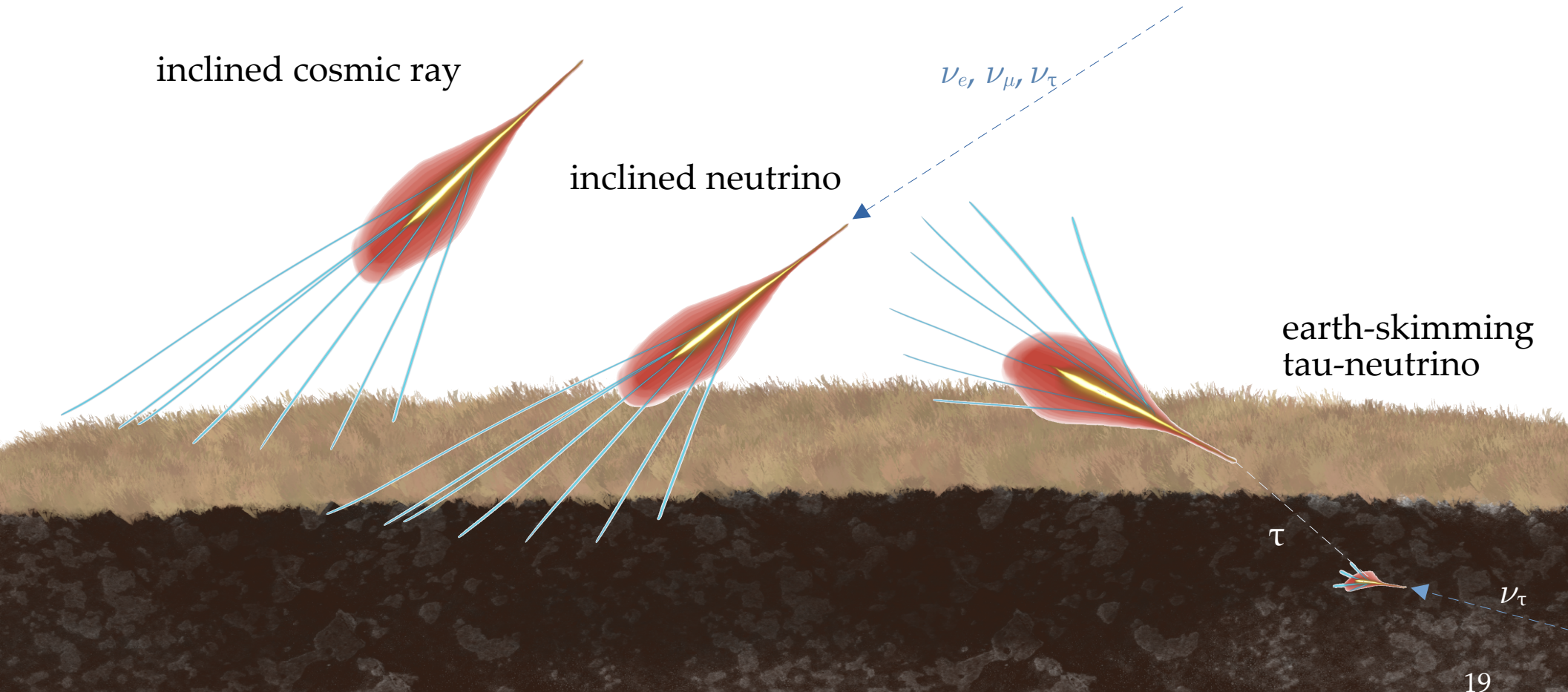
also produce γ and ν

→ *Cosmogenic*:

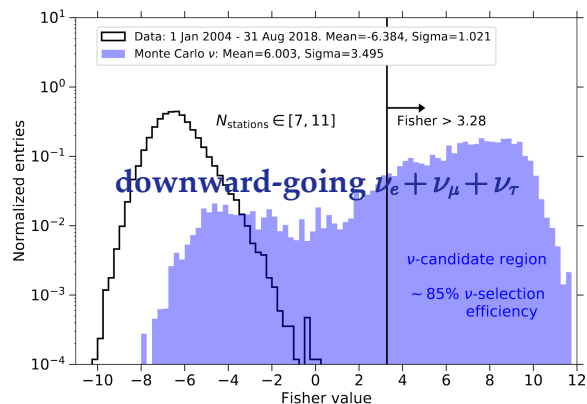
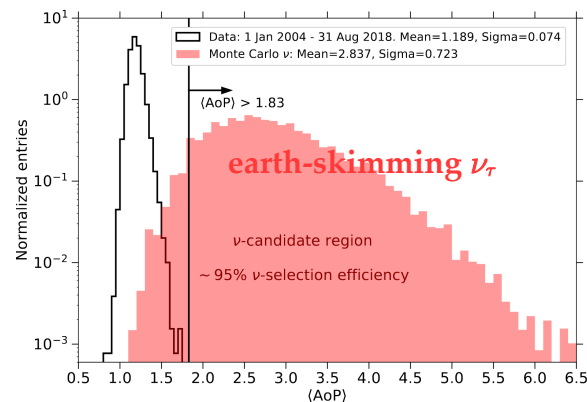
- interaction with CMB (GZK)
- interaction with matter (e.g. in galactic disk)
- decay of super-heavy dark matter



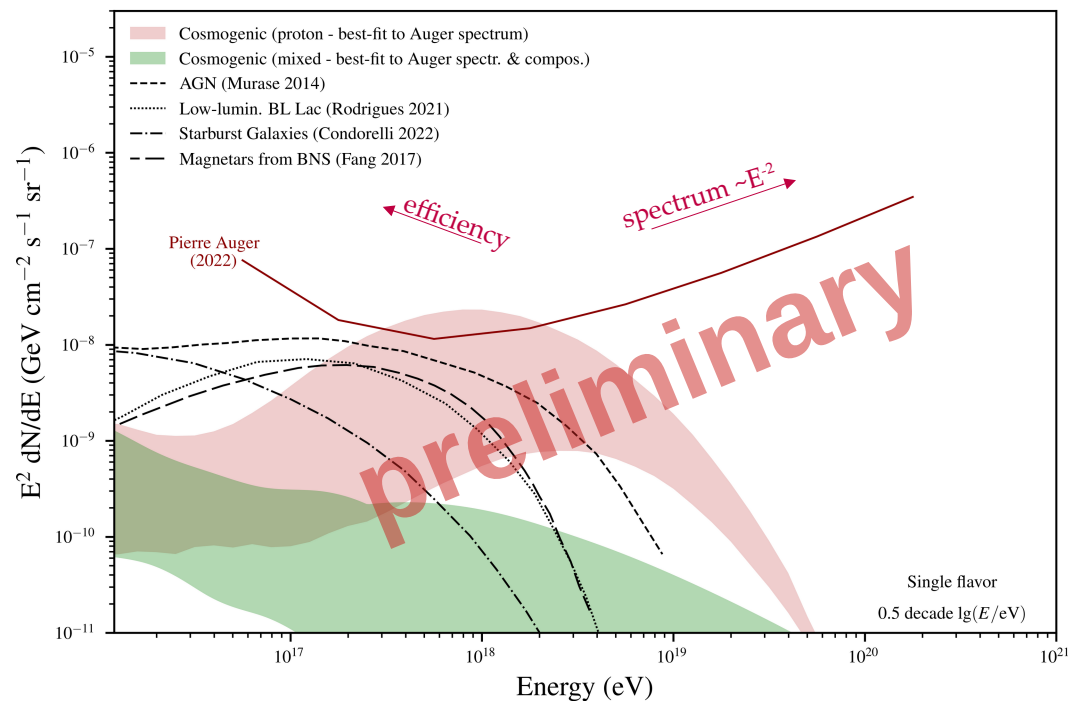
Neutrino induced air showers



Neutrinos in the EeV Energy Range

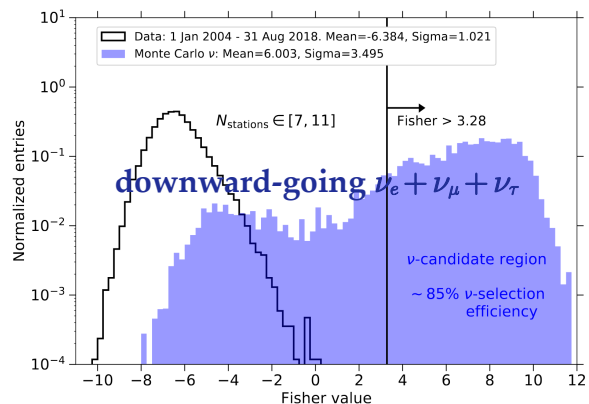
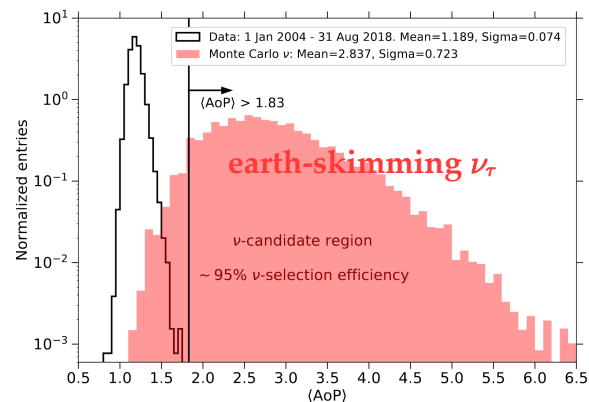


→ No candidate ν found

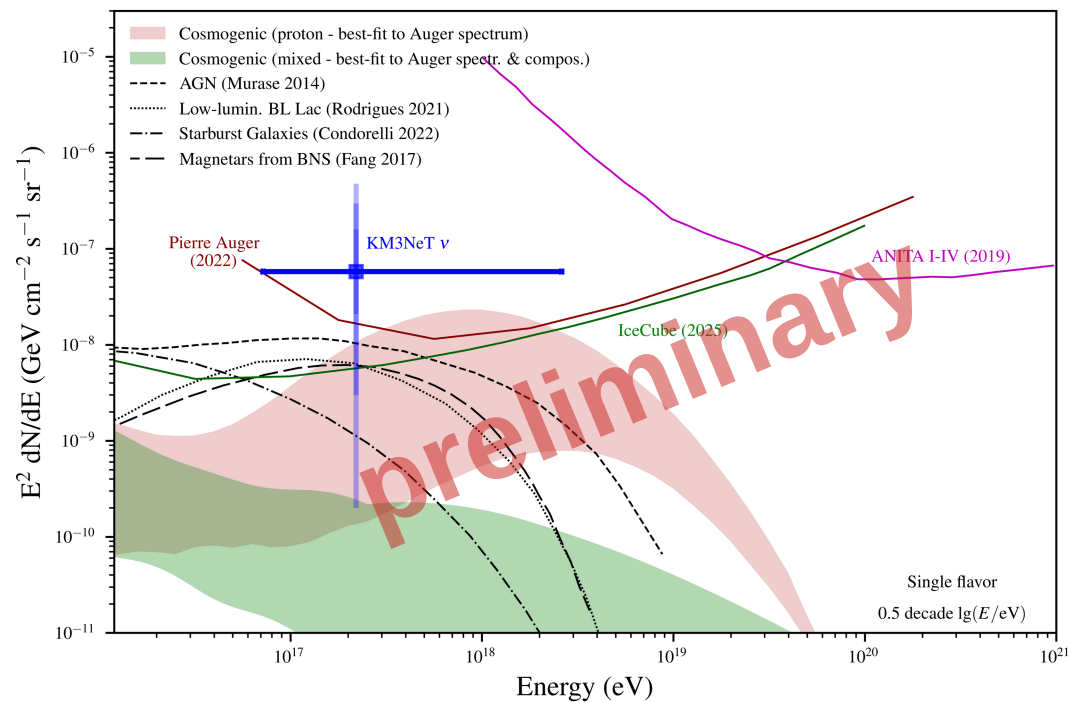


$$\nu_e : \nu_\mu : \nu_\tau = 1 : 1 : 1$$

Neutrinos in the EeV Energy Range



→ No candidate ν found



$$\nu_e : \nu_\mu : \nu_\tau = 1 : 1 : 1$$

Summary

- The Pierre Auger Observatory is a **observatory for UHE photons and neutrinos** as well
- **Stringent upper limits** on the diffuse γ and ν flux have been set
- **Follow-up searches** to transient events (e.g. gravitational wave events)
- The **AugerPrime** upgrade has the potential to further increase our sensitivity

