Highlights from the Pierre Auger Observatory

The Pierre Auger Collaboration

PIERRE AUGER OBSERVATORY

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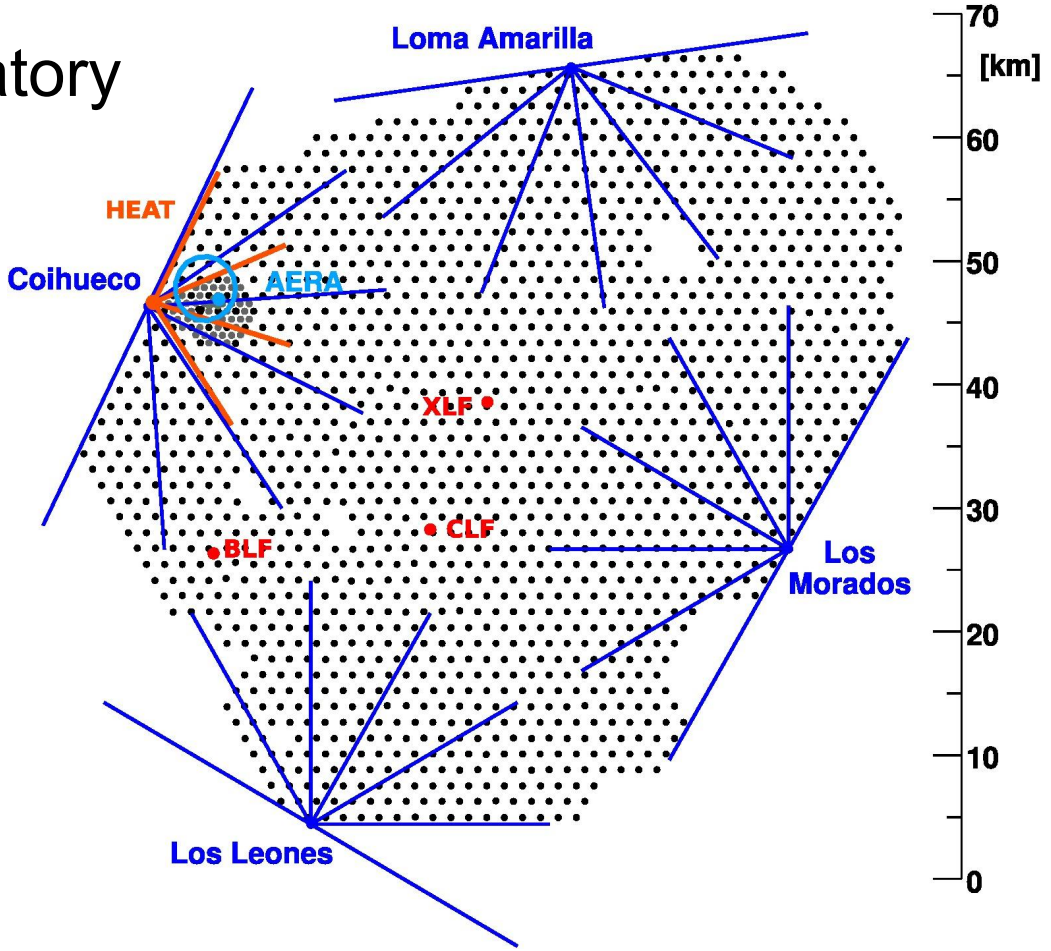
FAPESP
SÃO PAULO RESEARCH FOUNDATION

The Pierre Auger Collaboration

The Pierre Auger Observatory



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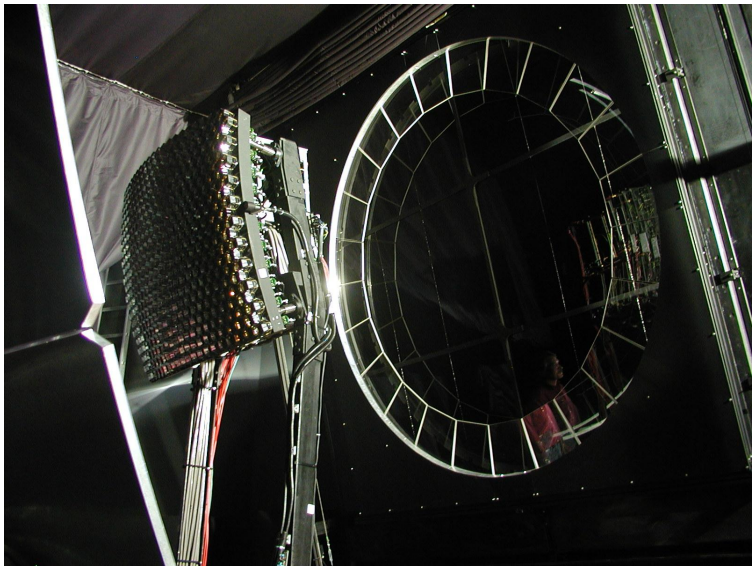
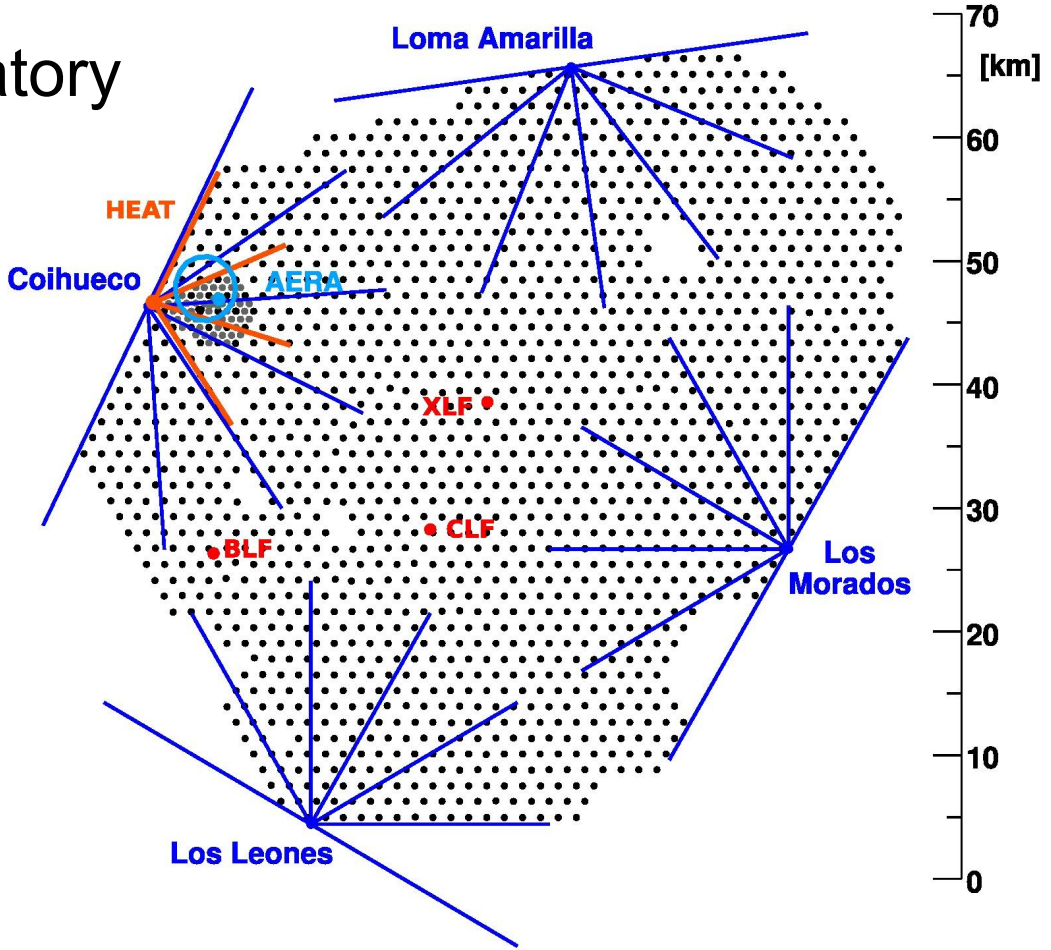
The Pierre Auger Observatory





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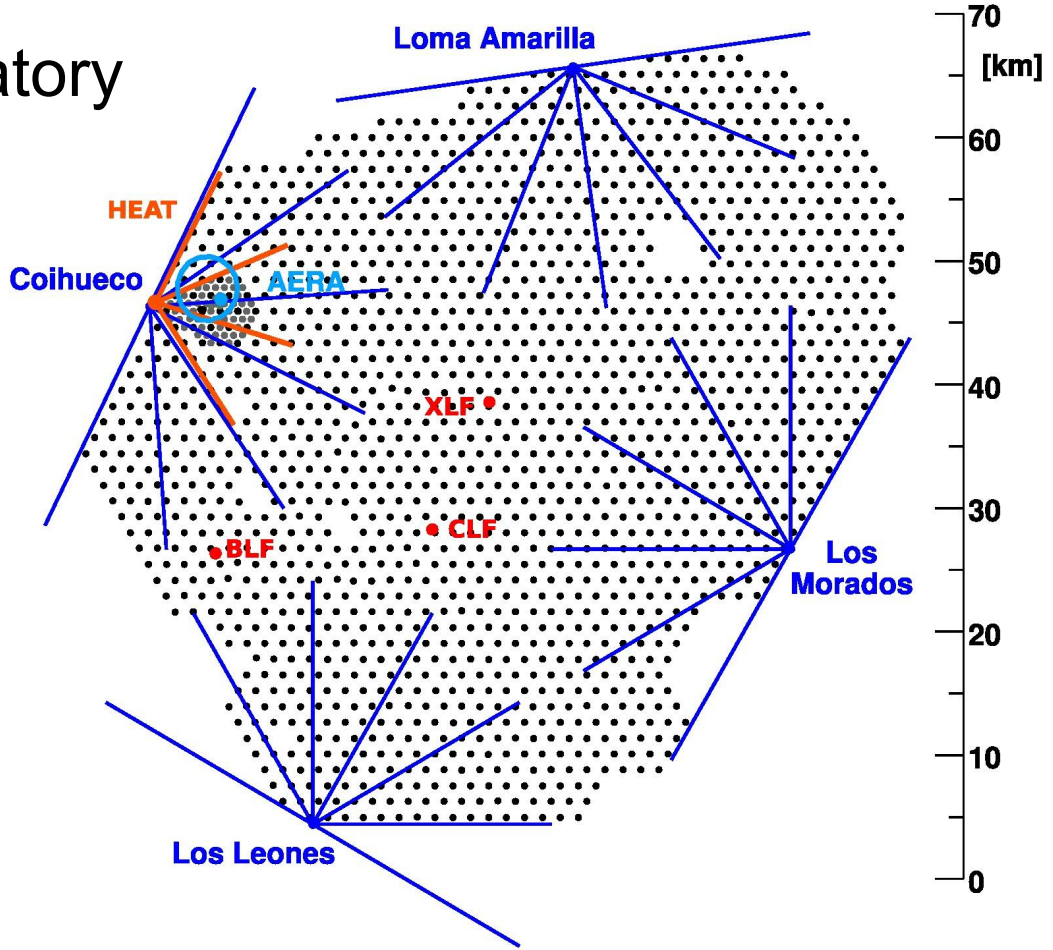
The Pierre Auger Observatory



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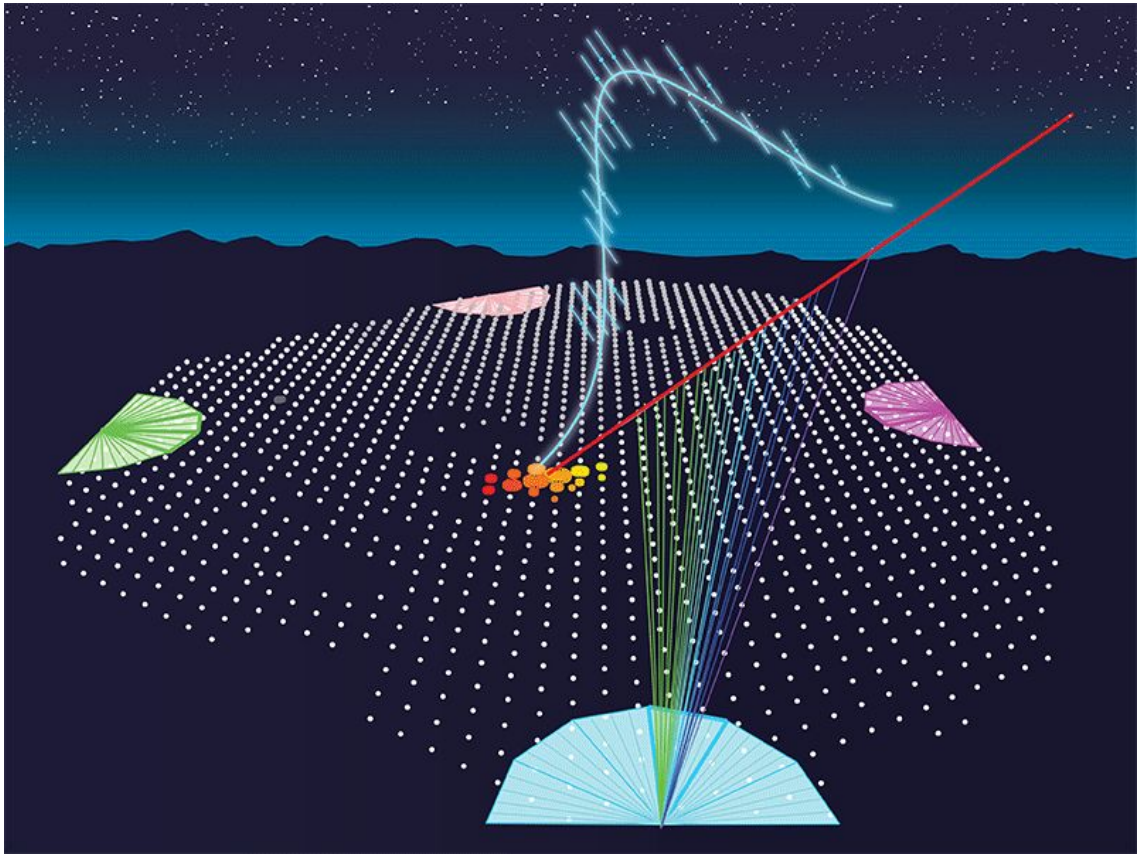
Data Analysis

Direction:
- Geometric reconstruction

Energy:
- Calorimetric measurement

Particle type estimator:
- Xmax



JINST 15 (2020) P10021, JINST 12 (2017) P02006, JCAP 08 (2014) 19 and NIM A 798 (2015) 172-213

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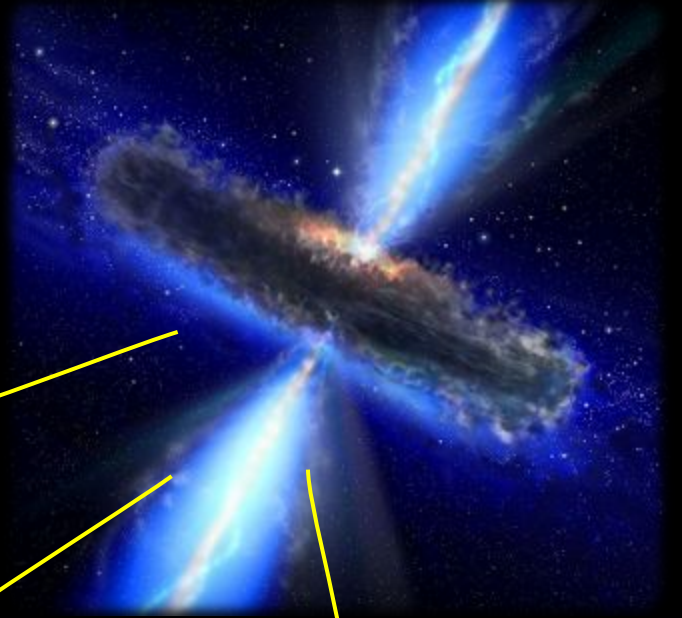
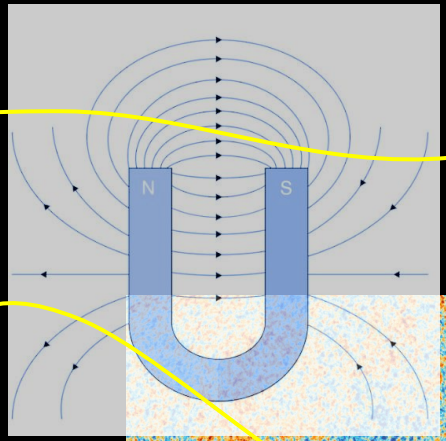
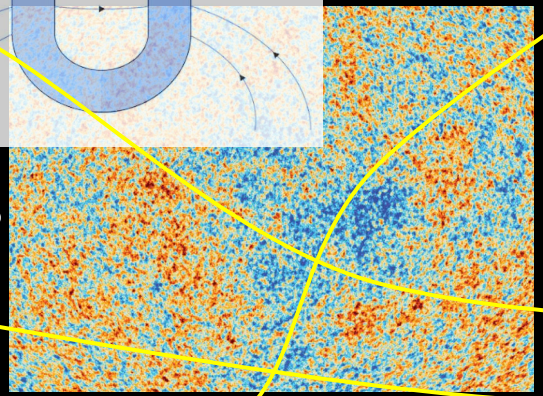
The Pierre Auger data teaches us about:

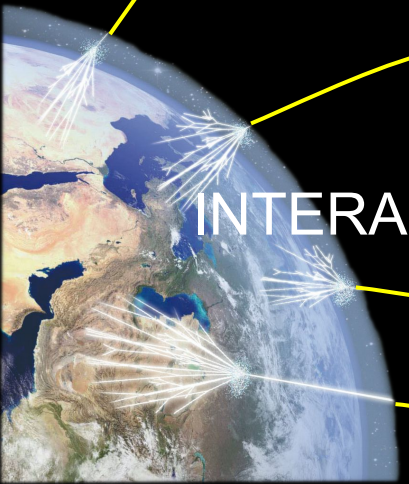


SOURCES



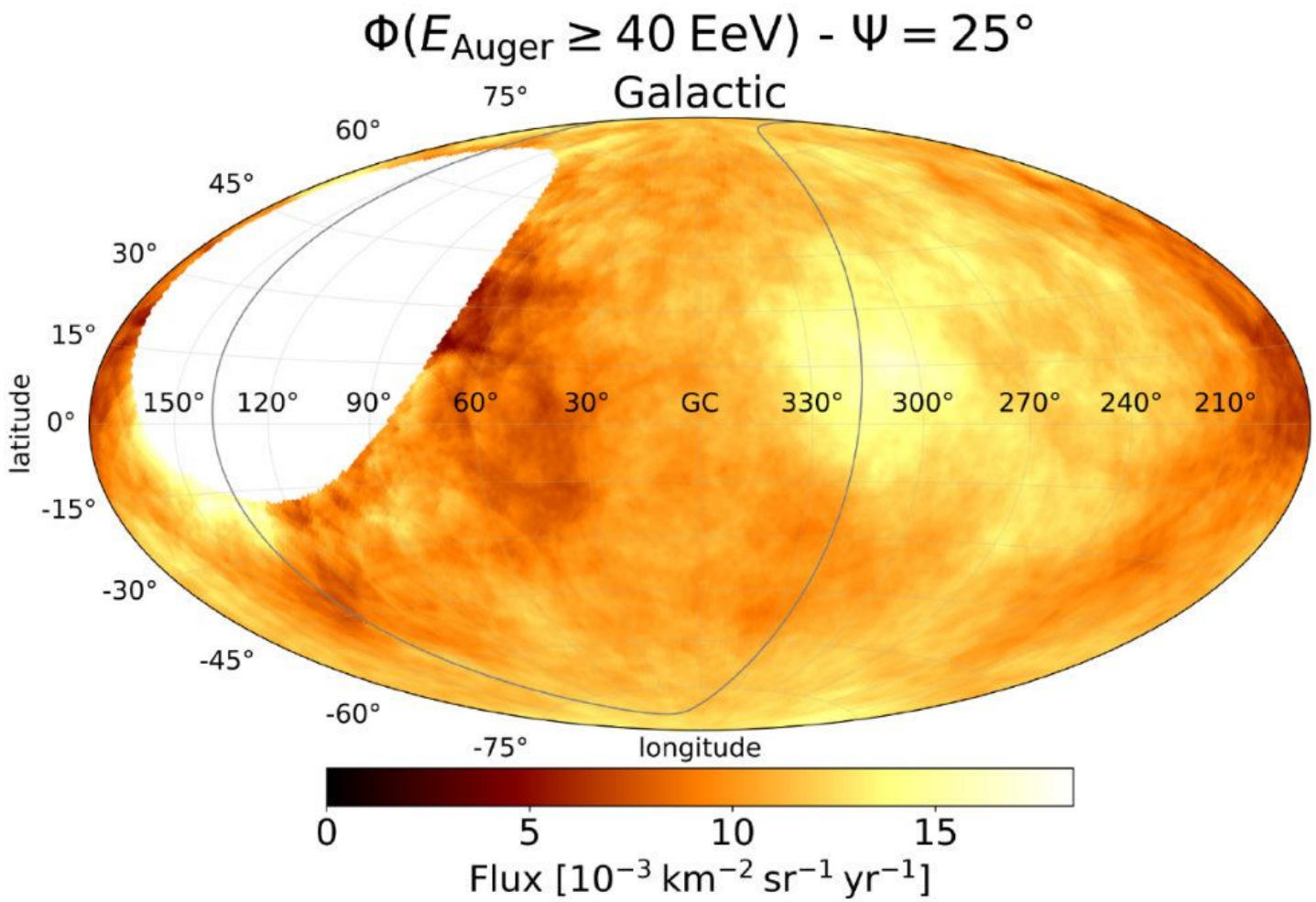


PATH



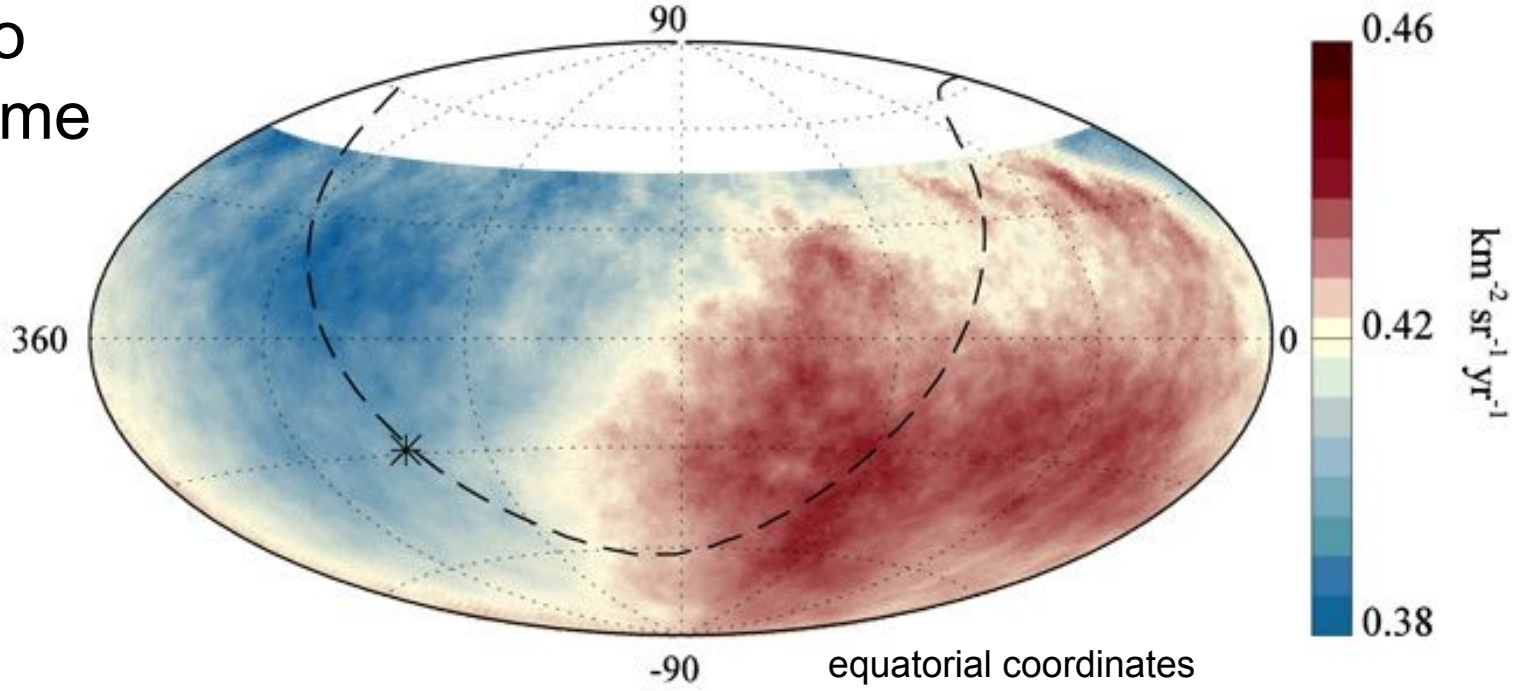
INTERACTIONS

Where do UHECR come from ?



Where do UHECR come from ?

Science 357 (2017)



- Dipole for $E \geq 8$ EeV: amplitude $d = (7.3^{+1.1}_{-0.9})\%$, at 6.6σ from isotropy
- Phase in R.A. $\alpha_d = 95^\circ \pm 8^\circ$ is nearly opposite to the Galactic center $\alpha_{GC} = -94^\circ$
- Magnitude and direction of dipole support extragalactic origin of UHECRs with $E > 4$ EeV

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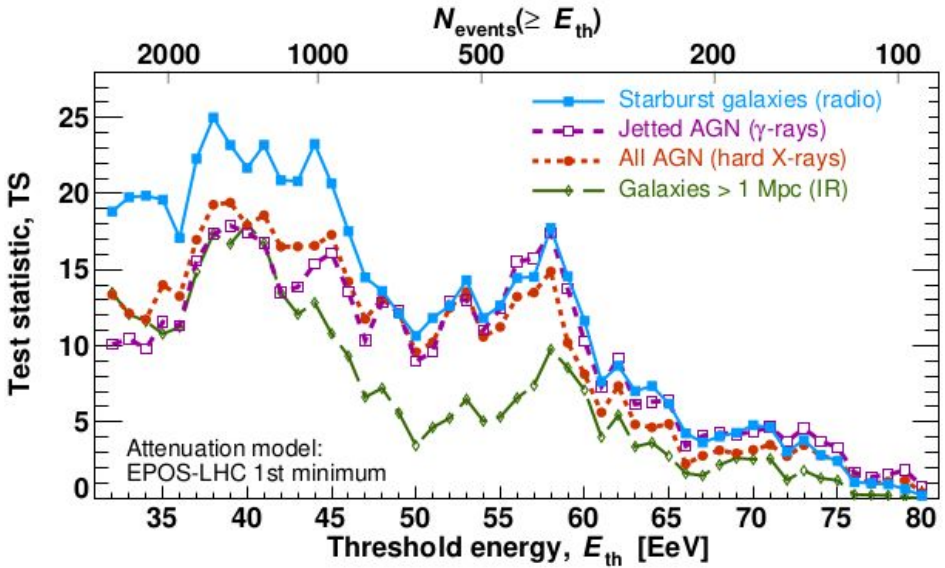
Correlation with known objects

Starburst galaxies

Significance 4.2σ, $E > 38$ EeV

γAGNs

Significance 3.3σ, $E > 39$ EeV



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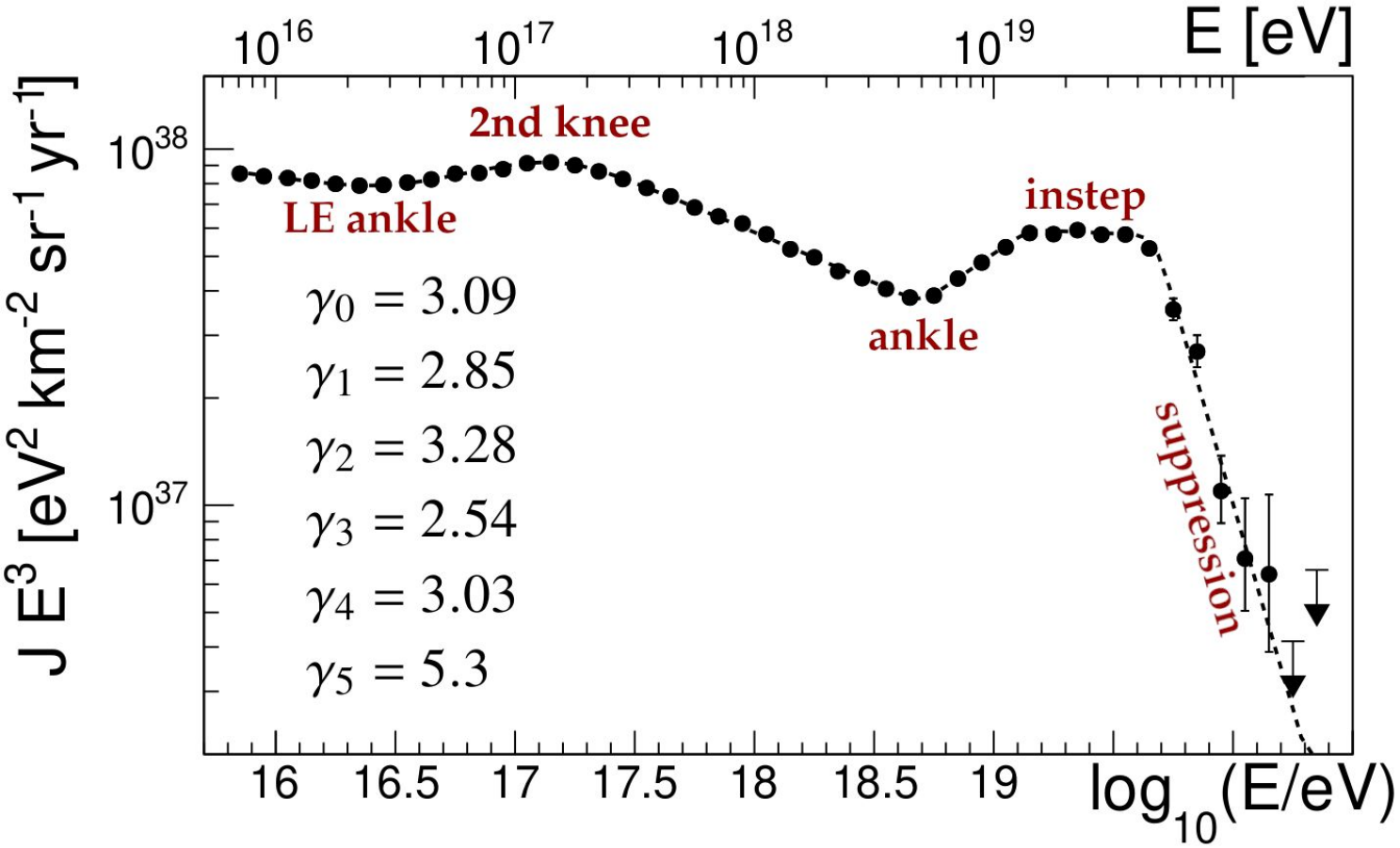
All-particle energy spectrum



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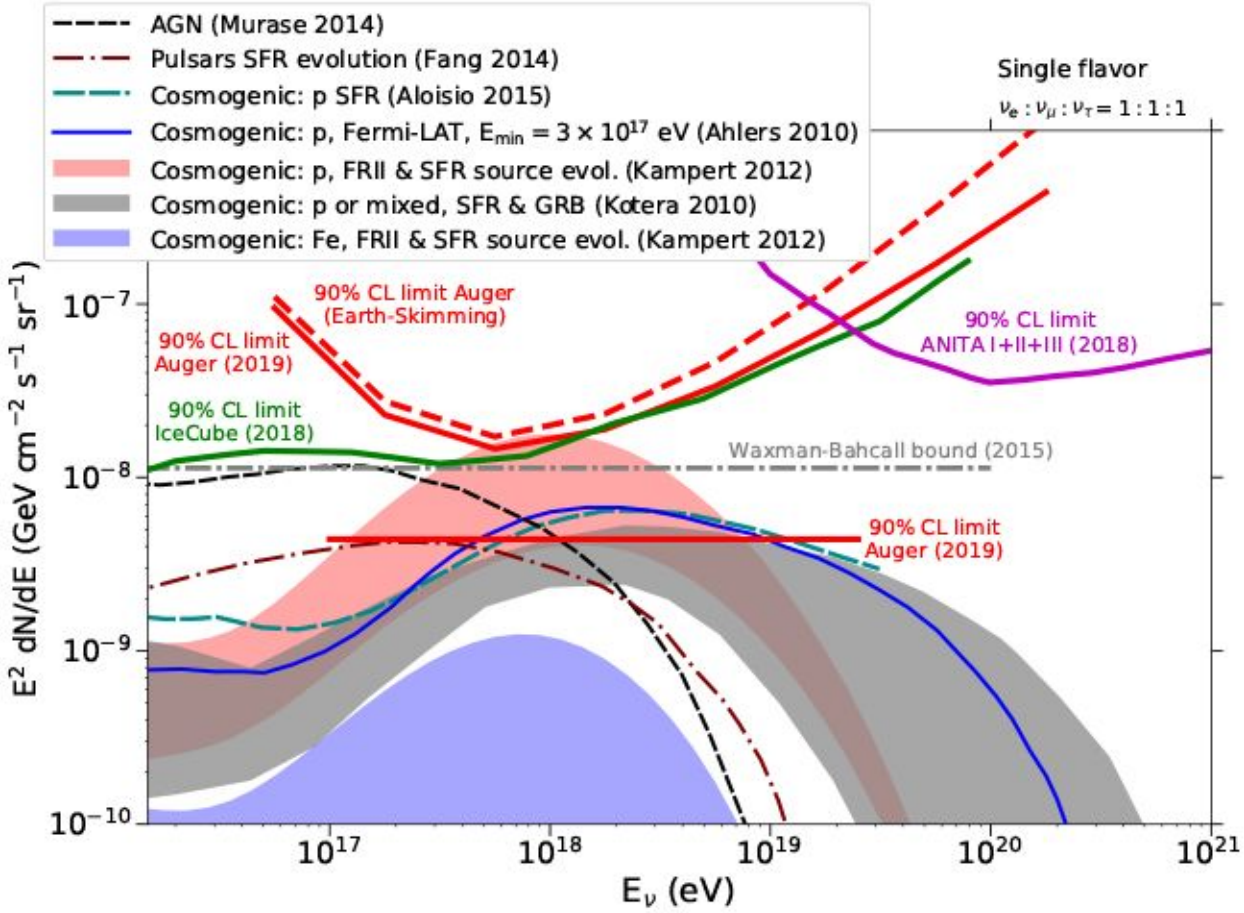
PRL 125 (2020) 121106, PRD 102 (2020) 062005, Eur. Phys. J. C 81 (2021) 966

Neutrinos



neutrino searches at Auger: JCAP 01 (2016) 037, PRD 94 (2016) 122007, ApJ Lett. 850 (2017) L35, JCAP 10 (2019) 022, 11 (2019) 004; ApJ 902 (2020) 105, PoS (ICRC 2023) 1488

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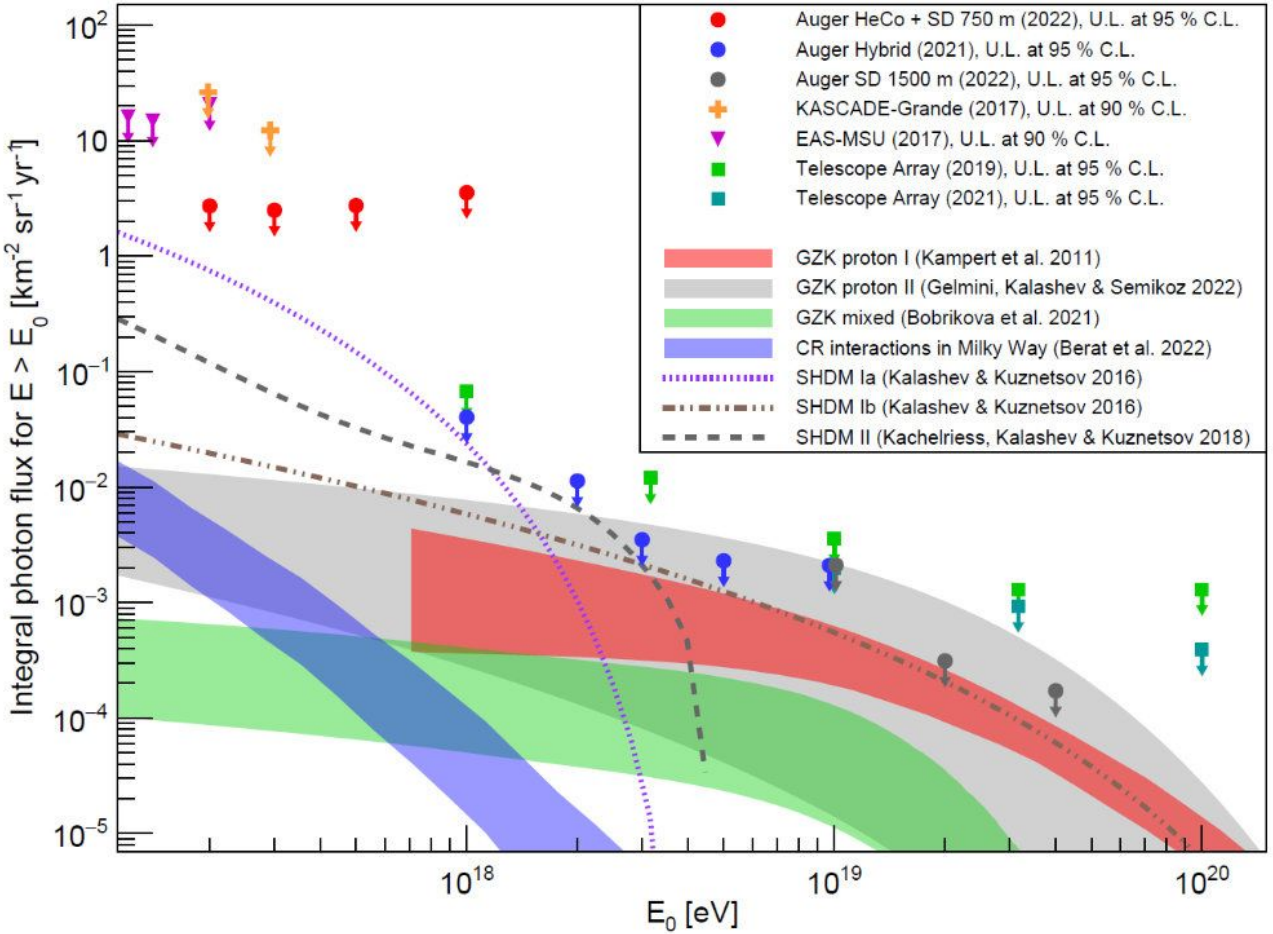
Photons



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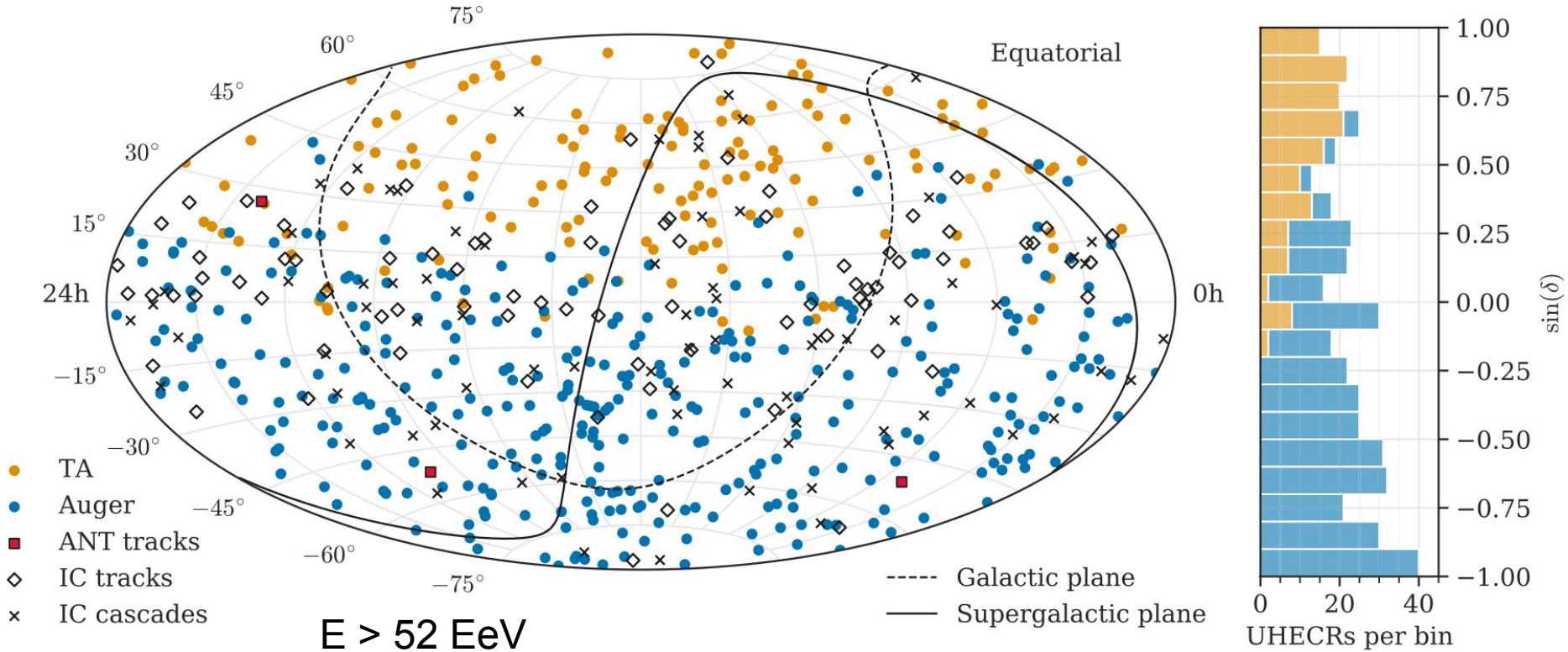
Universe 8 (2022) 579; ApJ, 933 (2022) 125; JCAP 05 (2023) 021

Neutrinos and UHECR correlation
IceCube and ANTARES and Auger and TA



E > 52 EeV

No significant correlation observed

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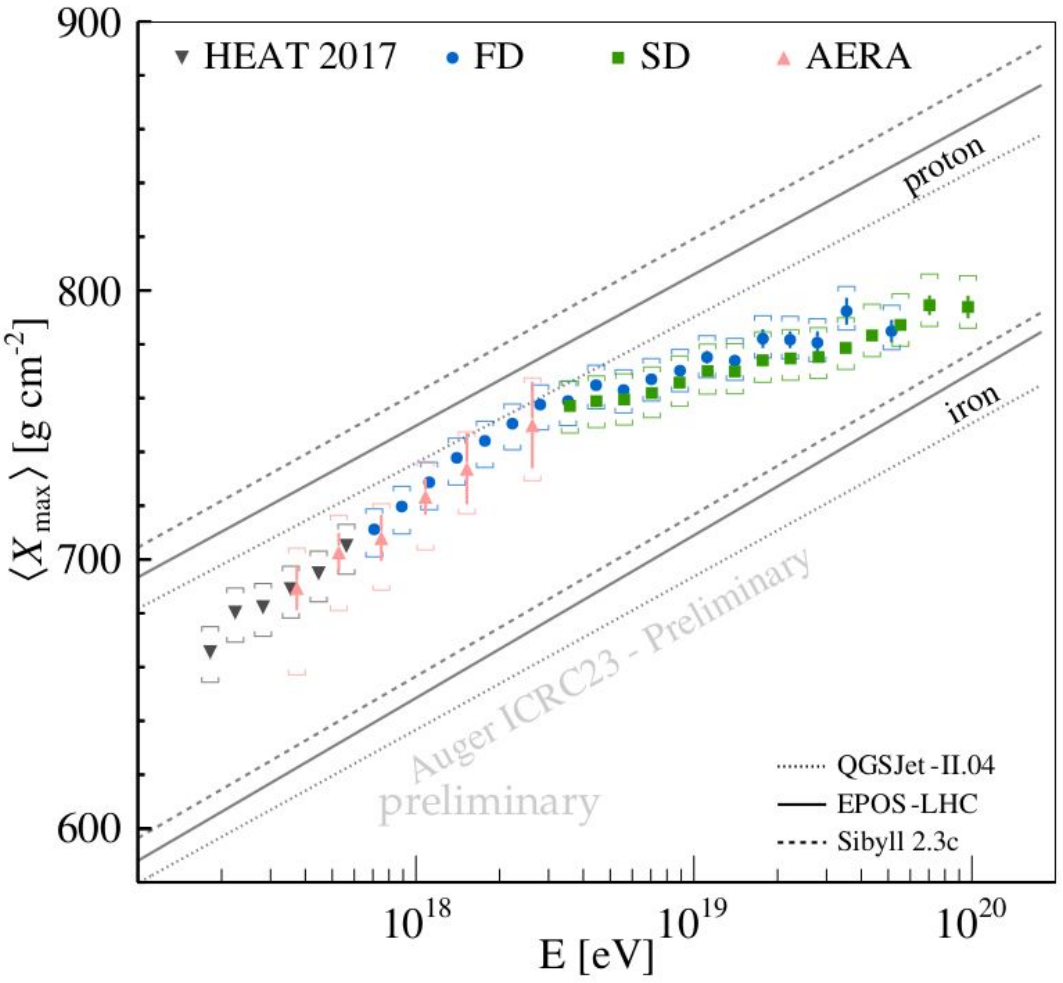
Xmax



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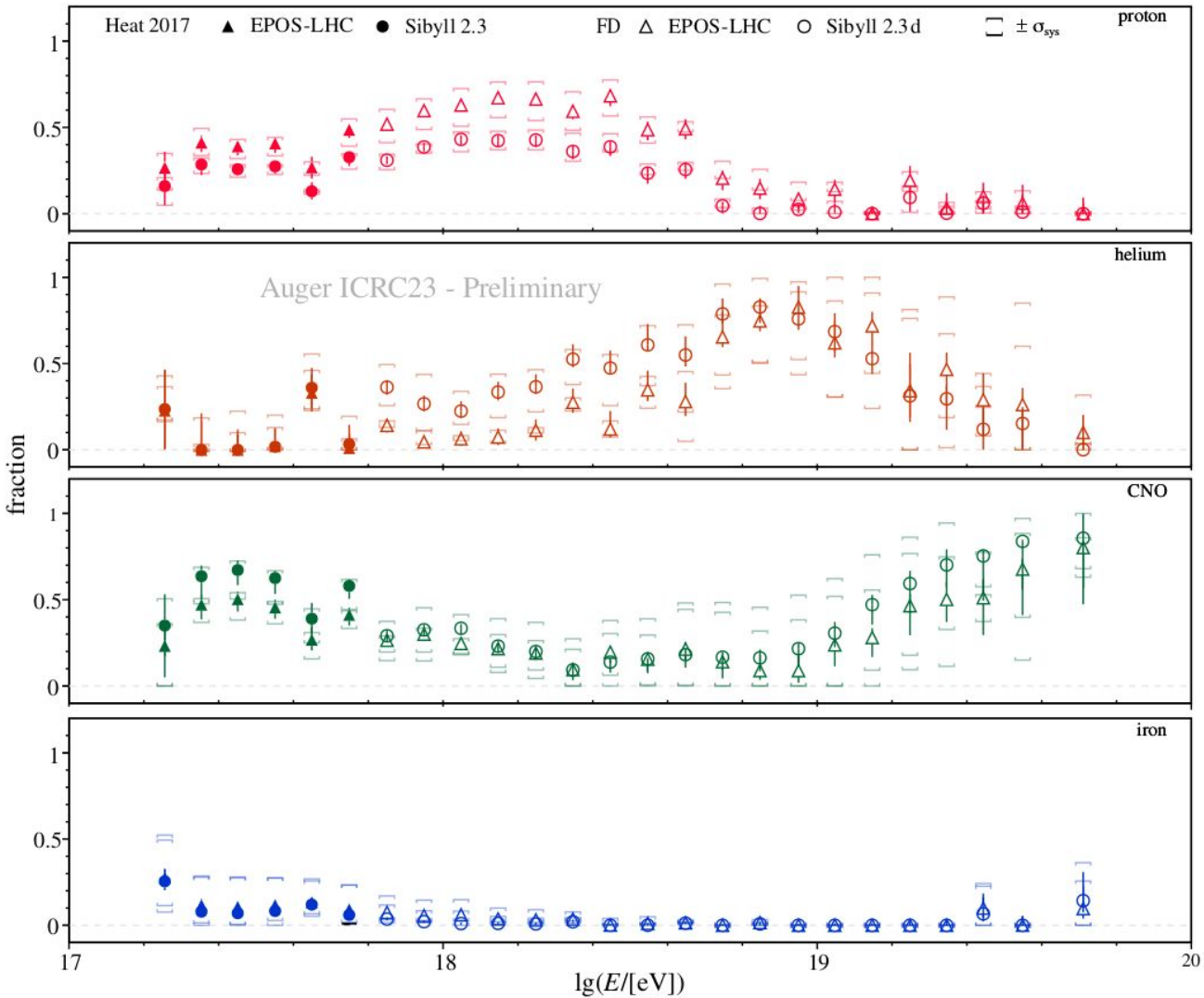
Phys. Rev. D 90 (2014) 122005, POS (ICRC2023) 365.

Composition



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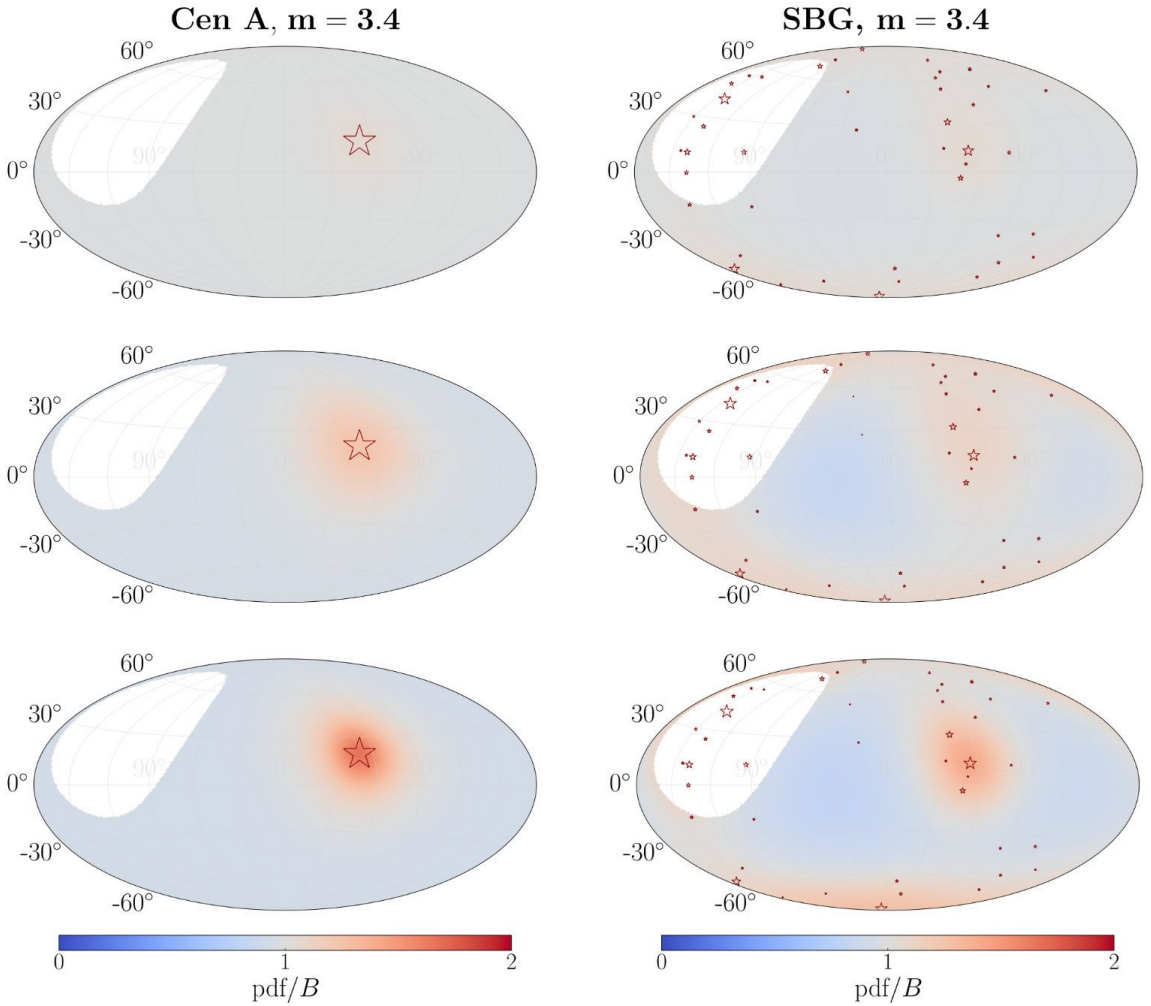
Correlation with known objects



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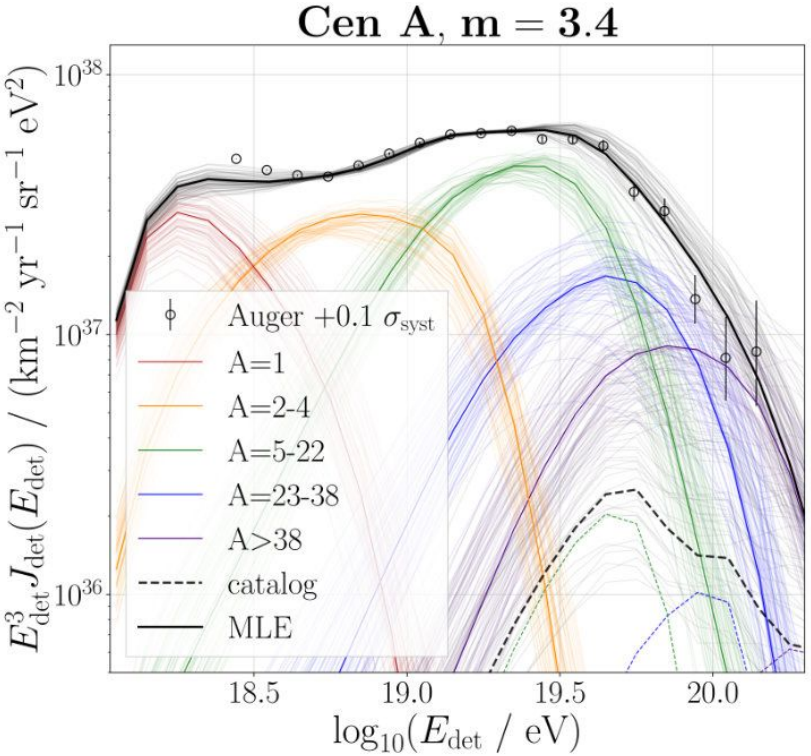
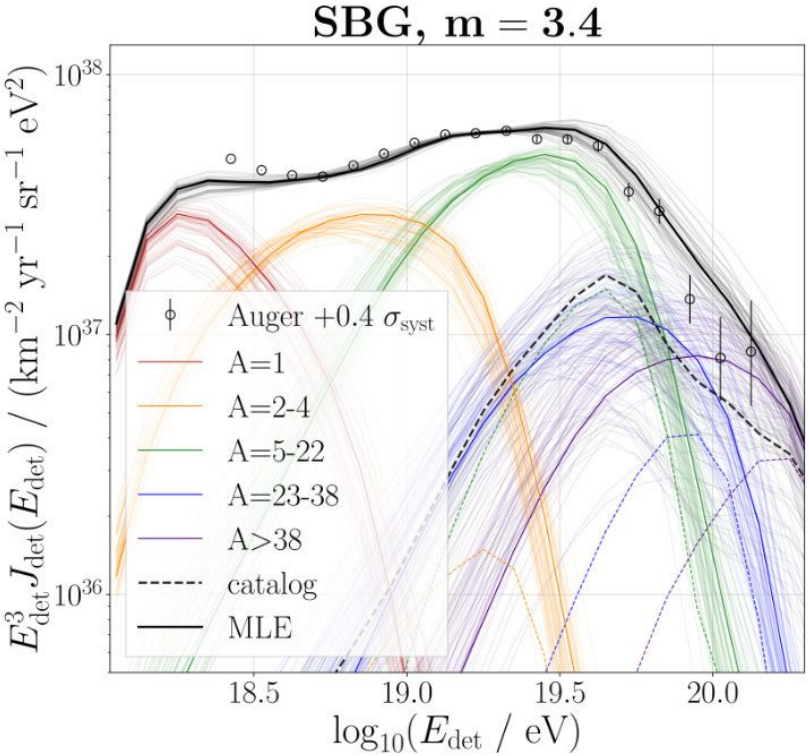
Correlation with known objects





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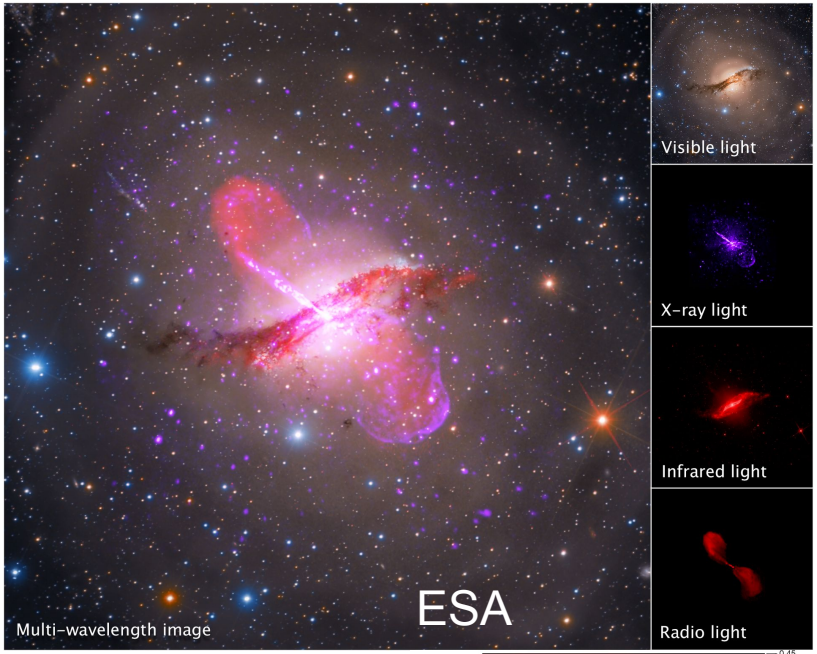
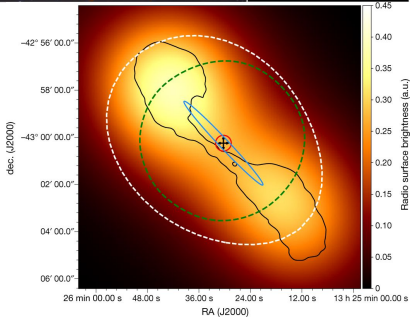
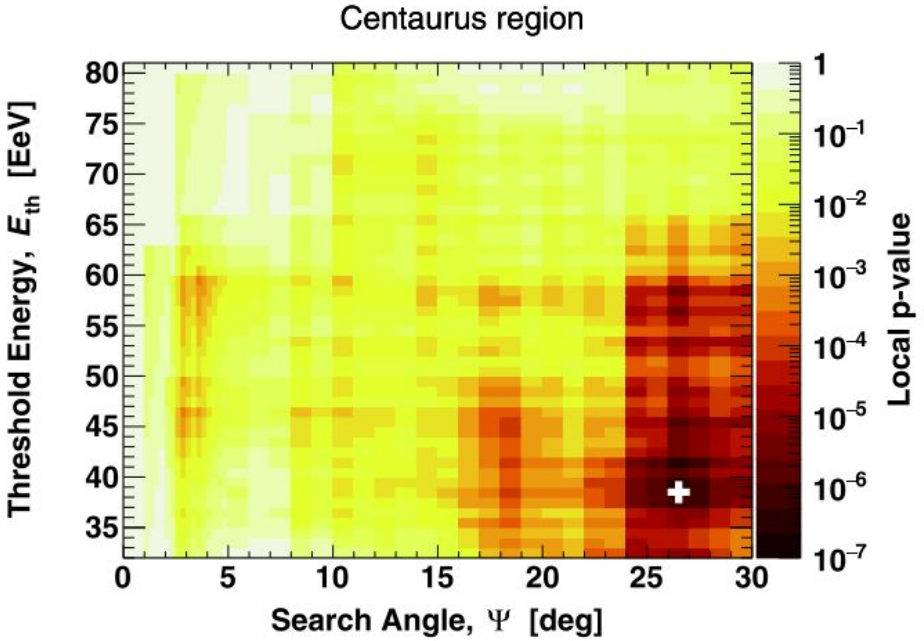
Centaurus A



H.E.S.S
Nature 582, 356–359 (2020)





Nobs = 215
Nexp = 152.0 from isotropy
p-value = 4.5×10^{-5}

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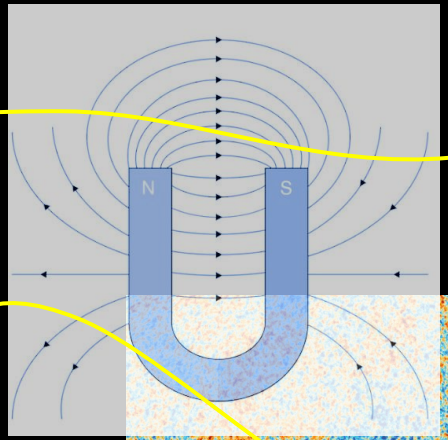
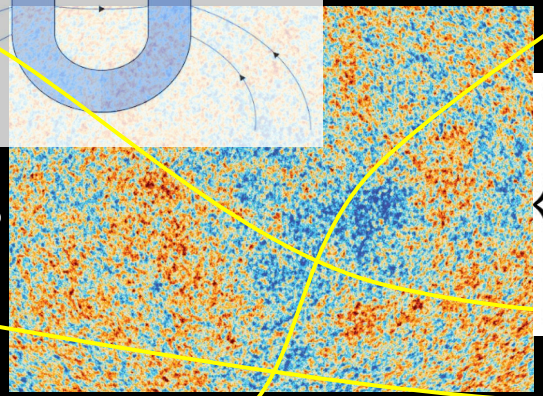
Propagations:
Lorentz Invariance Violation

SOURCES



PATH

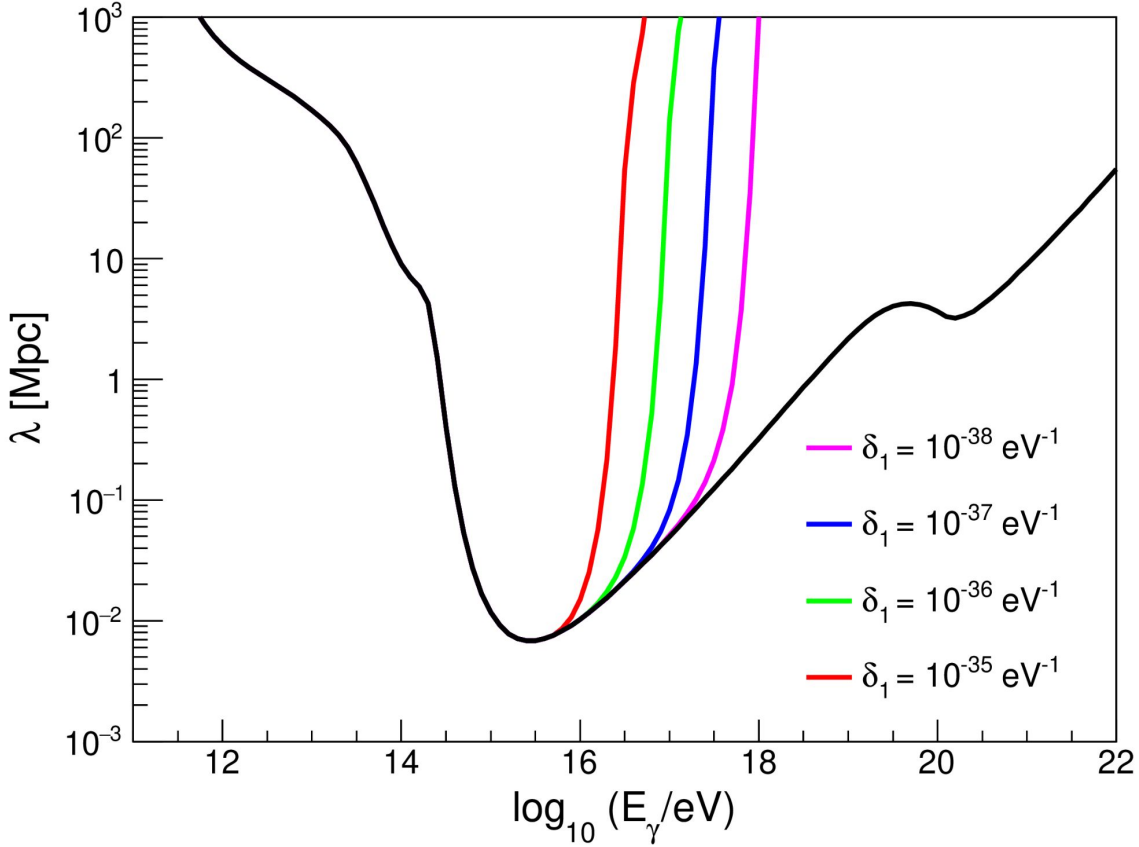
INTERACTIONS



$$\begin{cases} A + \gamma_{CB} \rightarrow (A-1) + p \\ p + \gamma_{CB} \rightarrow p + \pi^0 \\ \gamma + \gamma_{CB} \rightarrow e^+ + e^- \end{cases}$$

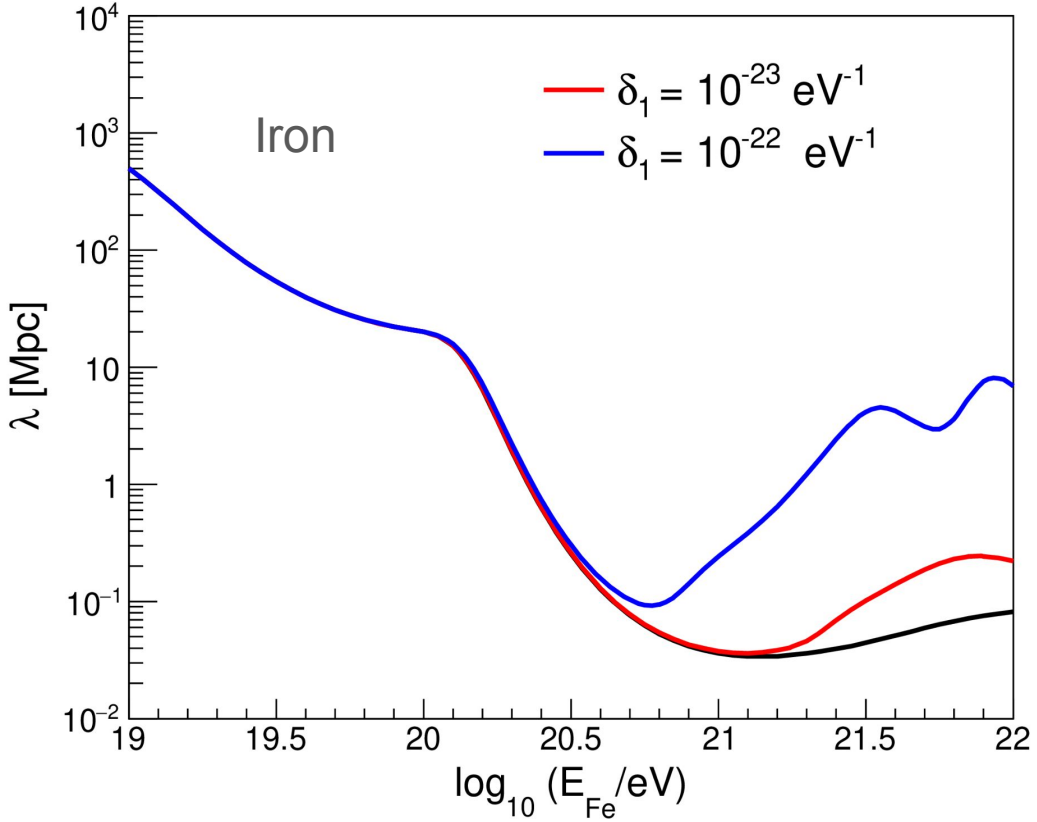
$$E^2 = p^2c^2 + m^2c^4 + \delta_1 p^3 c^3 + \delta_2 (p^2c^2)^2 + (\cdots)$$

Pair production



$$E^2 = p^2c^2 + m^2c^4 + \delta_1 p^3 c^3 + \delta_2 (p^2 c^2)^2 + (\cdots)$$

Nuclear photo-disintegration



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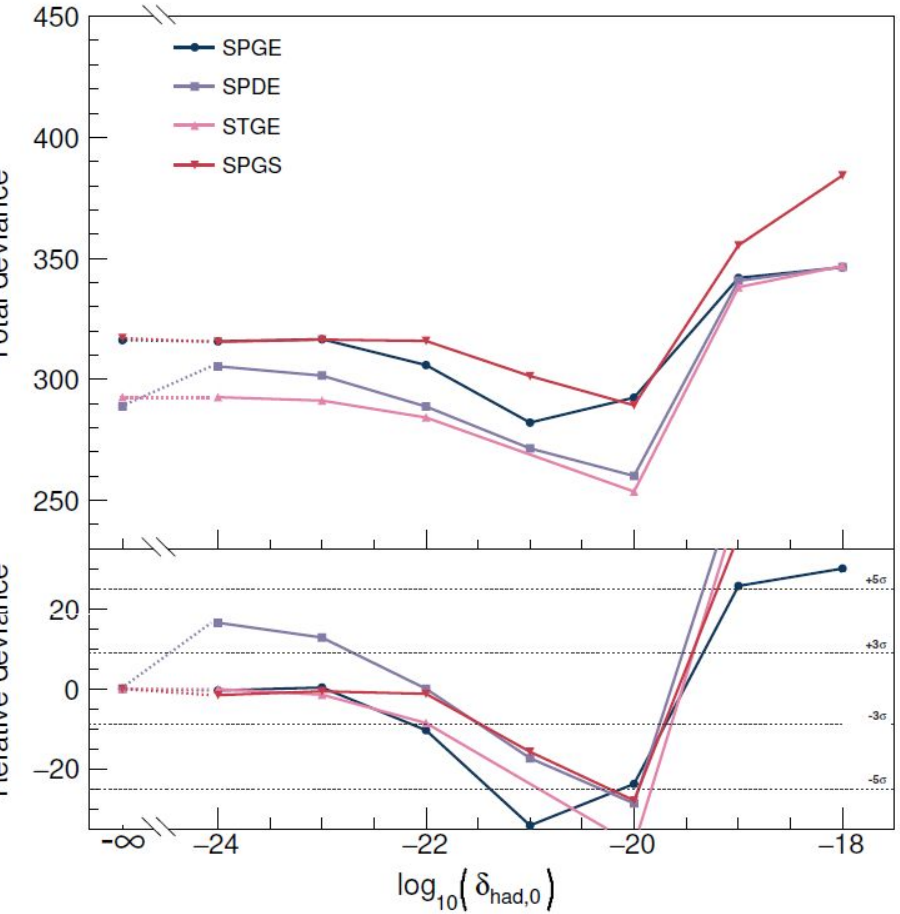
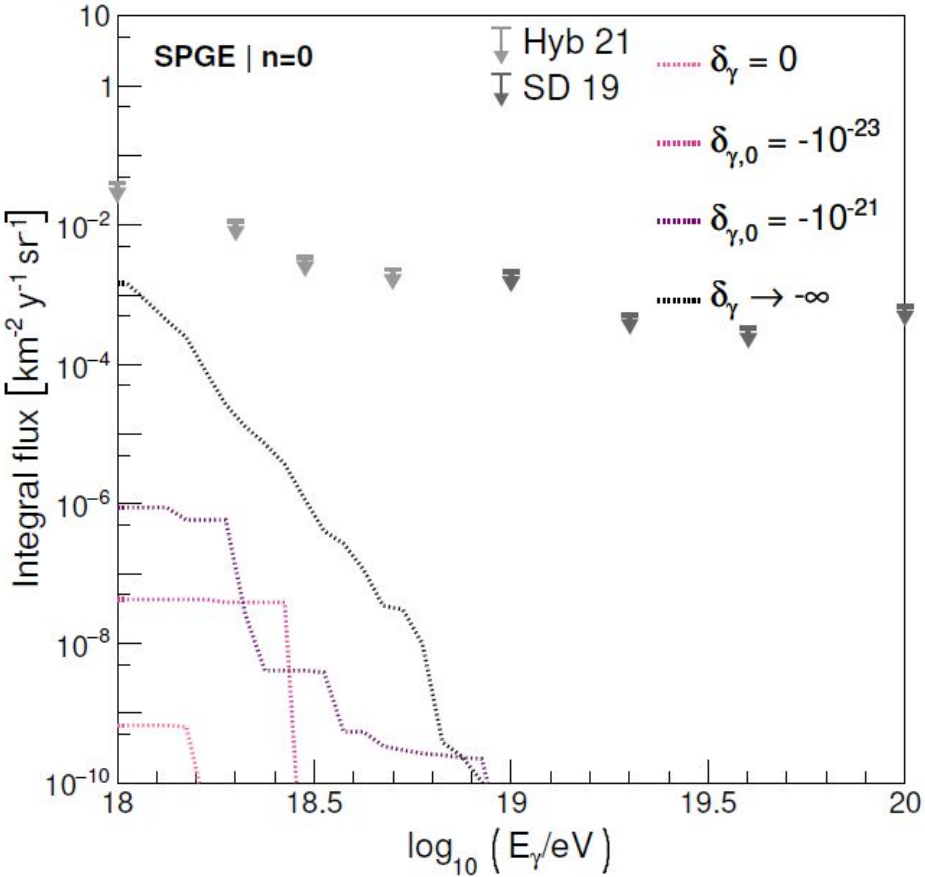
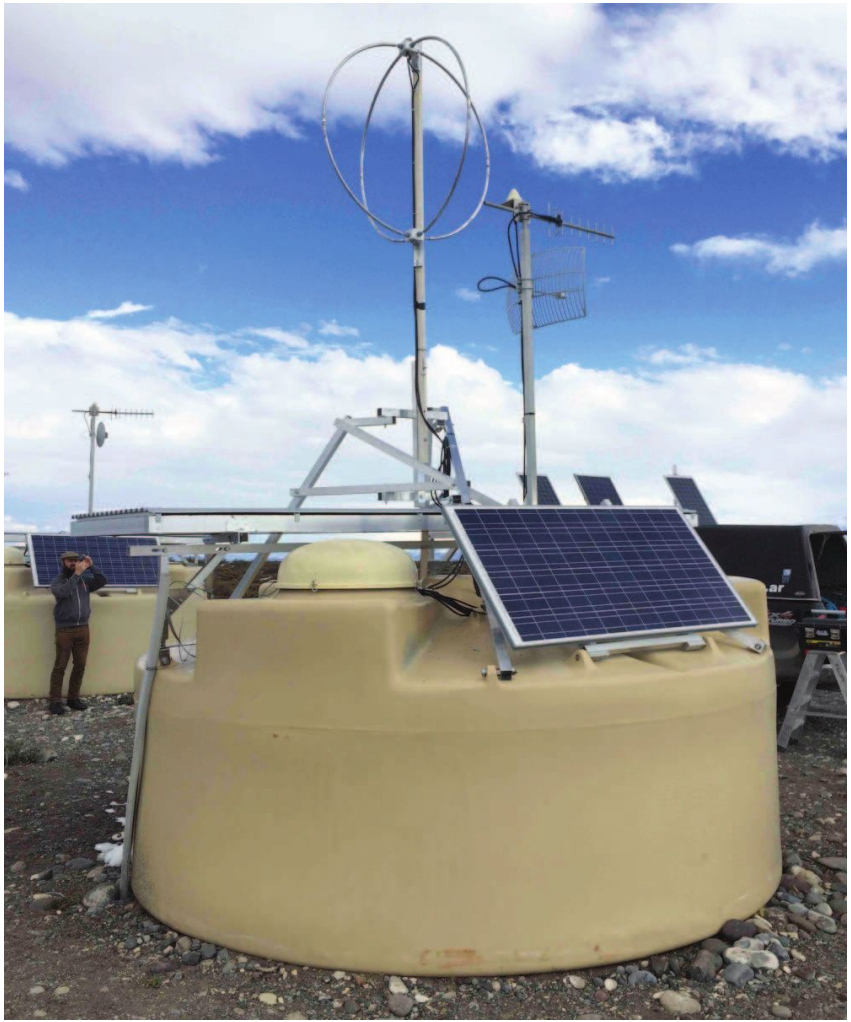

SPGE
SPDE
STGE
SPGS
Total deviance
Relative deviance
+5σ
+3σ
-3σ
-5σ
log10(δhad,0)


SPGE | n=0
Hyb 21
SD 19
δγ = 0
δγ,0 = -10-23
δγ,0 = -10-21
δγ → -∞
Integral flux [km-2 y-1 sr-1]
log10 (Eγ/eV)

AugerPrime

- new electronics
- small PMT
- 3.8 m 2 scintillator detectors
- radio antenna
- underground muon detectors

Upgrade to run until 2035



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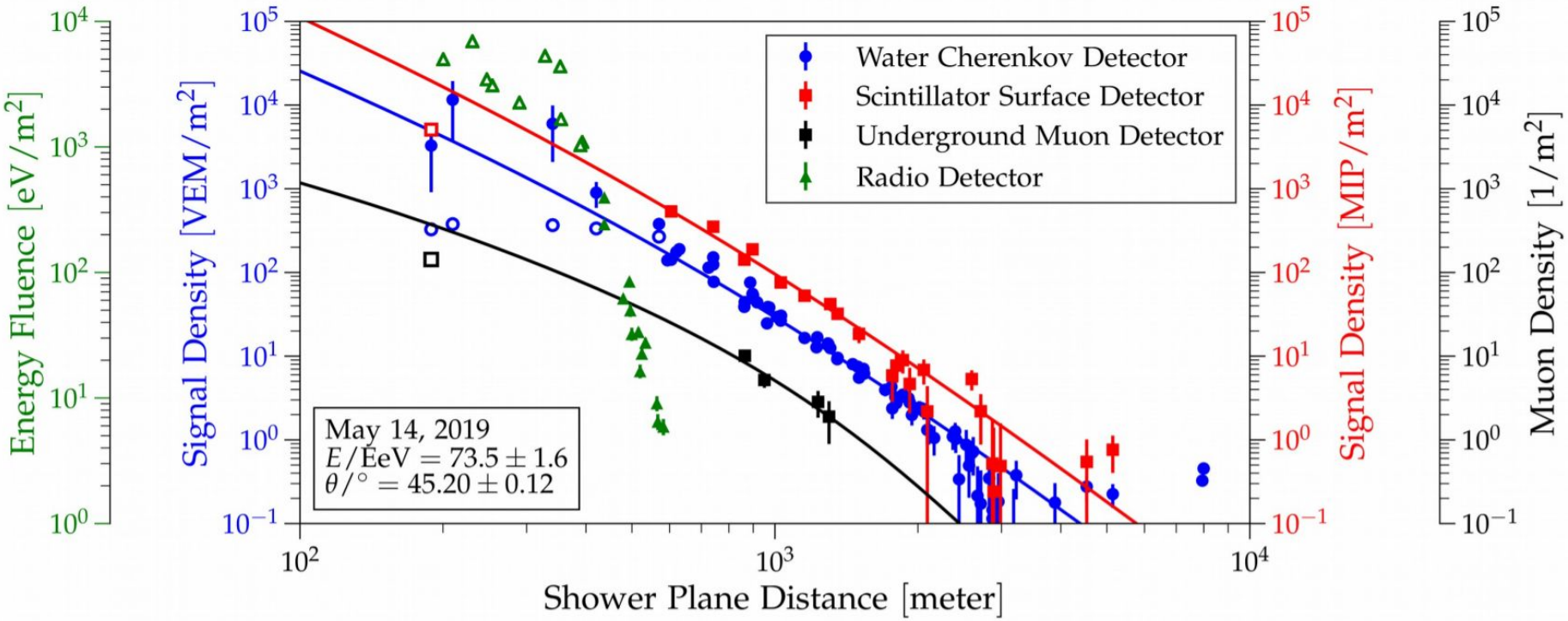
Identify a subset of protons with multi detectors



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Final remarks

- The Pierre Auger Observatory has produced several breakthrough results in the last two decades
- Until 2035 AugerPrime will measure high precision data with enhanced proton selection
- Stay tuned for more: https://www.auger.org/science/publications/journal-articles

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