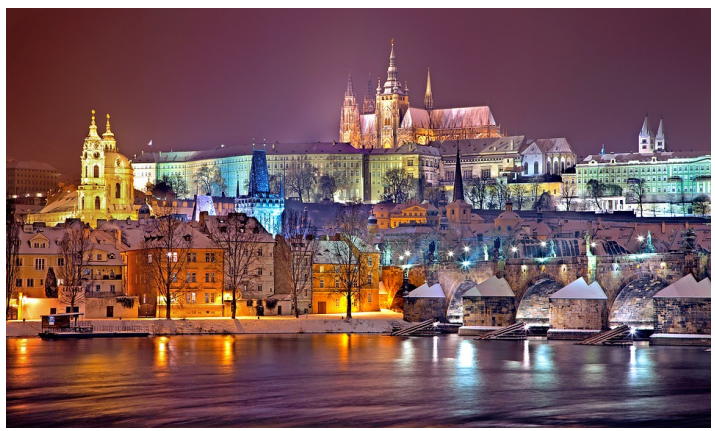
2022 report from the Auger-TA working group on UHECR arrival directions

A. di Matteo, L. Anchordoqui, T. Bister, R. de Almeida, O. Deligny, G. Farrar, U. Giaccari, G. Golup, R. Higuchi, J. Kim, M. Kuznetsov, I. Mariș, G. Rubtsov, P. Tinyakov, **F. Urban**[†]

For the Pierre Auger and Telescope Array collaborations

[†]CEICO, Institute of Physics of the Czech Academy of Sciences
Prague

UHECR 2022, L'Aquila – Italy, October 04, 2022



EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
Development and Education

MINISTRY OF EDUCATION, YOUTH AND SPORTS

the experiments

:: pierre auger observatory ::

365 collaborators in 90 institutions in 18 countries

i. Located at 35.2° S, 69.2° W, 1400 m a.s.l. (Mendoza Province, Argentina)

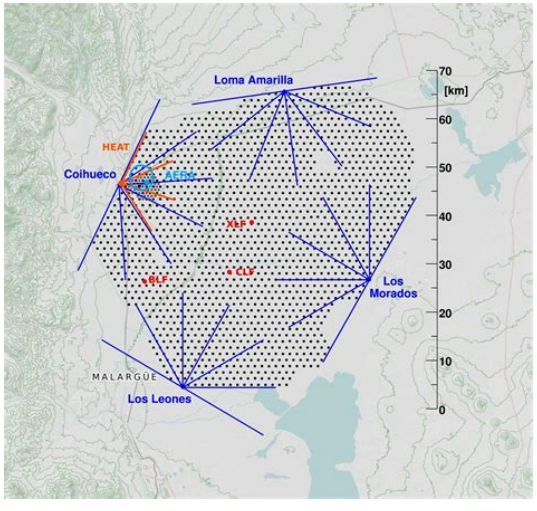
ii. Main SD array: 1600 water Cherenkov detectors in a 1.5 km triangular grid

iii. Can detect showers with zenith angles up to 80° (northernmost declination visible: +44.8°)

iv. Taking data since 01 Jan 2004

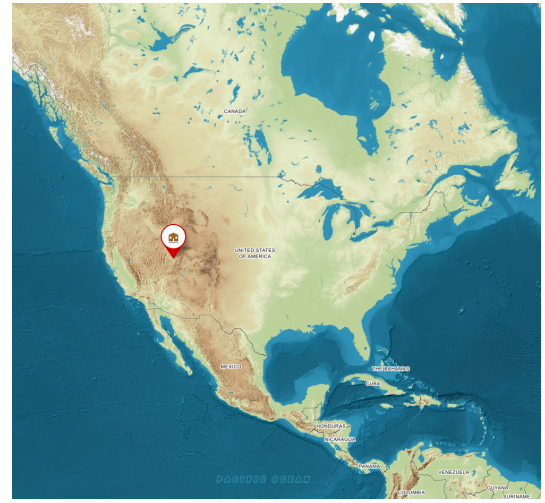
v. Current dataset: events up to 31 Dec 2020 (17 yr = ICRC)

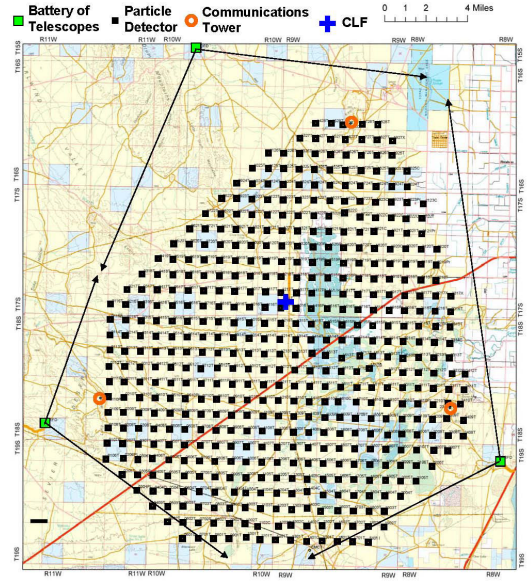
   a. 124,000 km² yr sr effective exposure
   b. 39,691 events with $E_{\mathrm{Auger}} \geq 8.53$ EeV
   c. 2635 events with $E_{\mathrm{Auger}} \geq 32$ EeV



:: Telescope Array ::

140 collaborators in 32 institutions in 7 countries





i. Located at 39.3° N, 112.9° W, 1400 m a.s.l. (Millard County, Utah, USA)

ii. Main SD array: 507 plastic scintillator detectors in a 1.2 km triangular grid

iii. Can detect showers with zenith angles up to 55° (southernmost declination visible: −15.7°)

iv. Taking data since 11 May 2008

v. Current dataset: events up to 10 May 2022 (14 yr = ICRC + 3 yr)

   a. 18,000 km^2 yr sr effective exposure
   b. 6014 events with $E_{\mathrm{TA}} \geq 10$ EeV
   c. 395 events with $E_{\mathrm{TA}} \geq 40.5$ EeV

:: exposures ::

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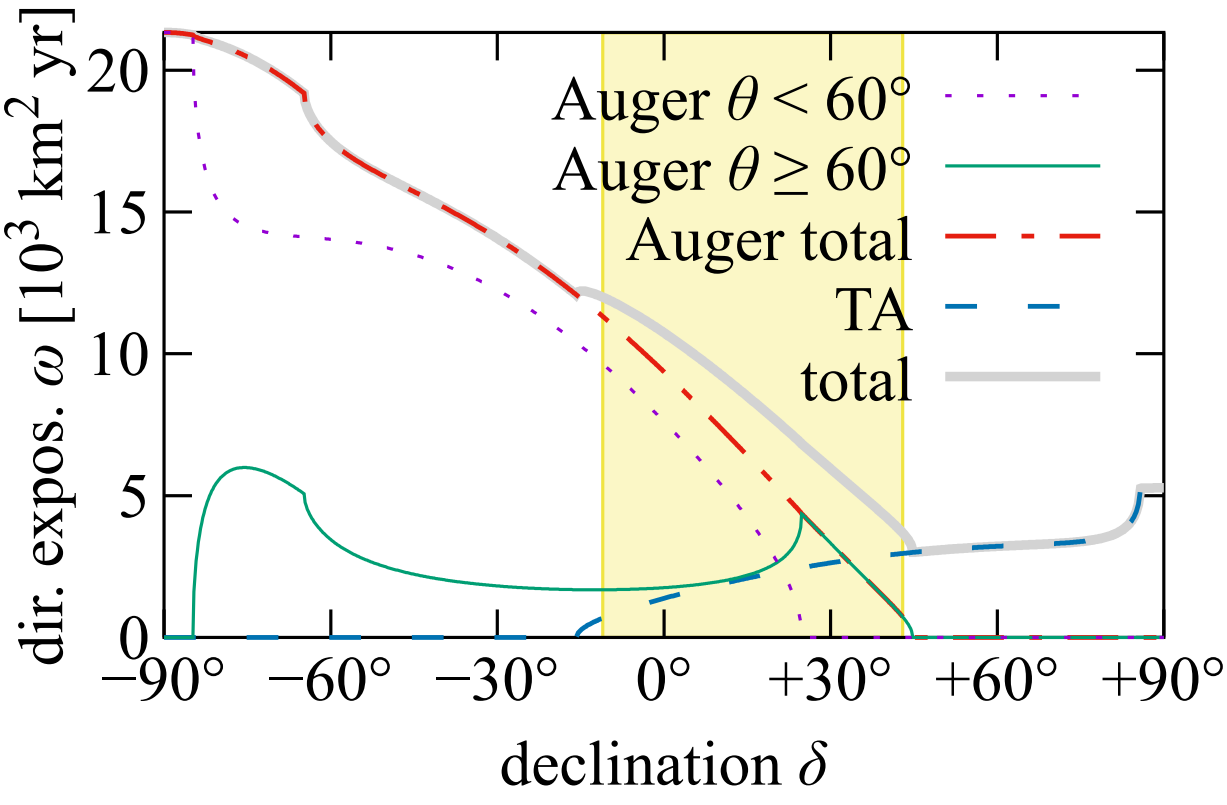
their FOVs overlap near the equator



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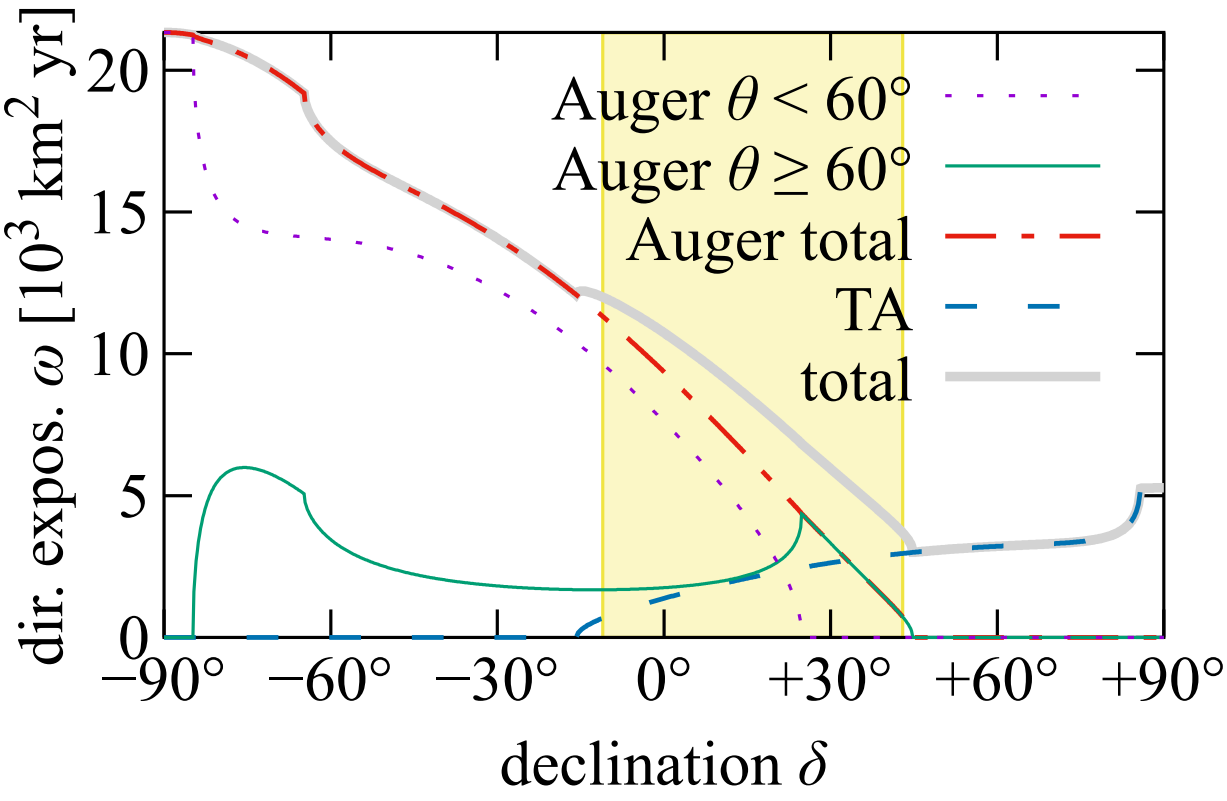

so we can:

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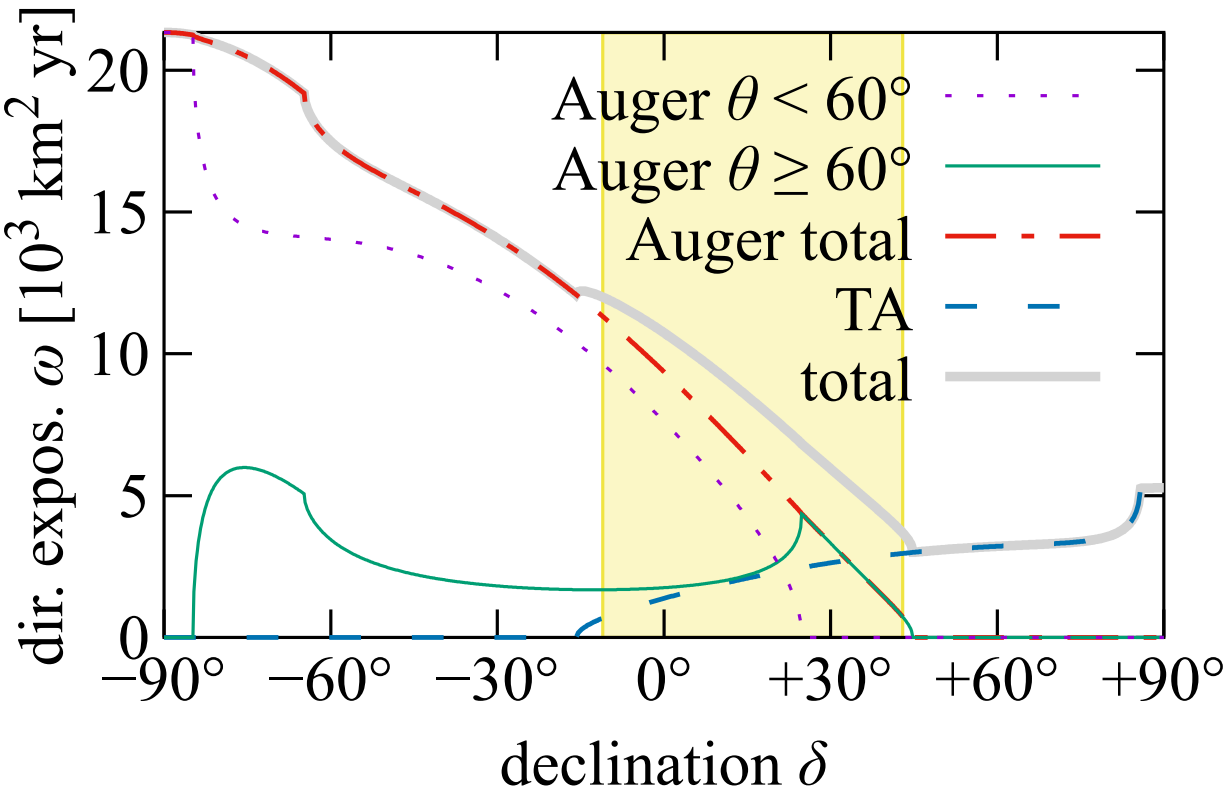

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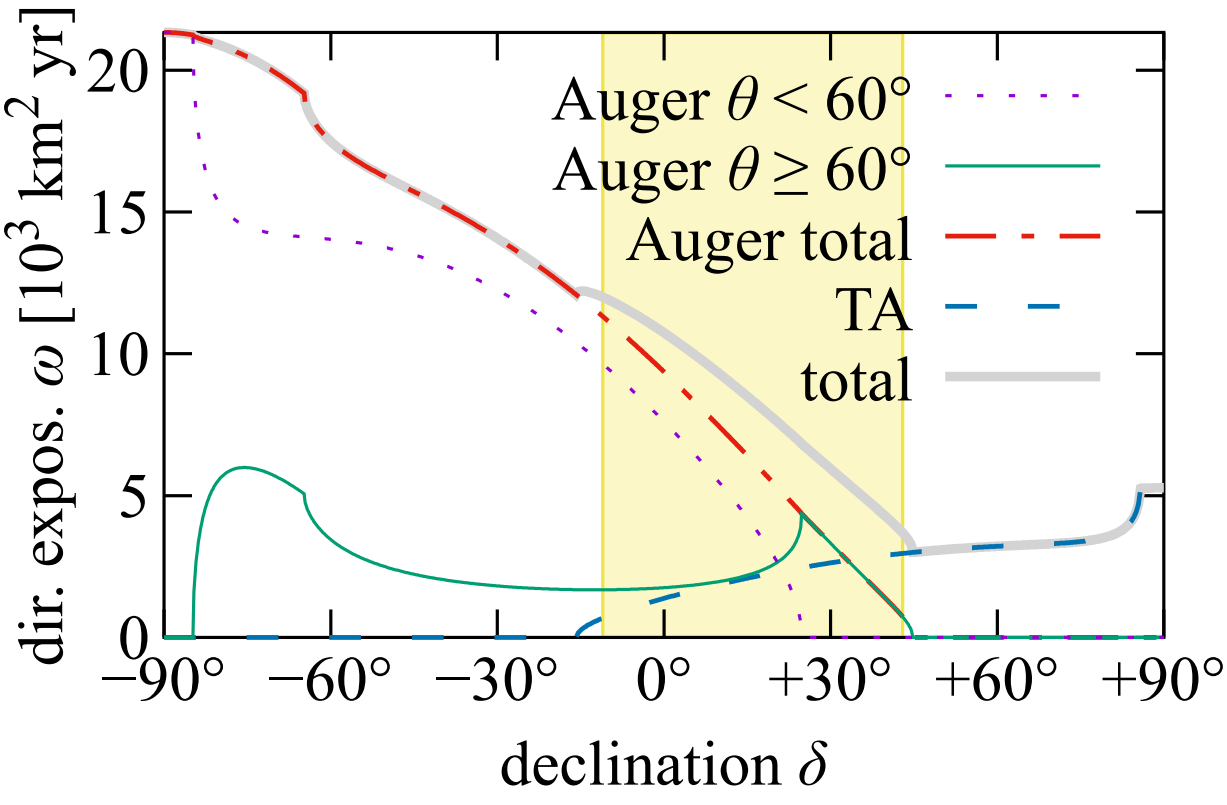

so we can: **cross-calibrate** the flux and **assume "nothing"** about the flux

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i. The energies of UHECR events are affected by systematic uncertainties: $\delta E_{\rm sys} = 14\%$ for Auger and $\delta E_{\rm sys} = 21\%$ for TA

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iv. Assume a power-law relationship © Tinyakov [Auger and TA collabs.] ICRC2021

$$E_{\rm Auger} = \hat{E}\, e^{\alpha} (E_{\rm TA}/\hat{E})^{\beta} \quad \text{and} \quad E_{\rm TA} = \hat{E}\, e^{-\alpha/\beta} (E_{\rm Auger}/\hat{E})^{1/\beta}$$

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v. PS: this conversion must NOT be used outside of this study

see talk by V Verzi for Auger-TA spectrum WG results

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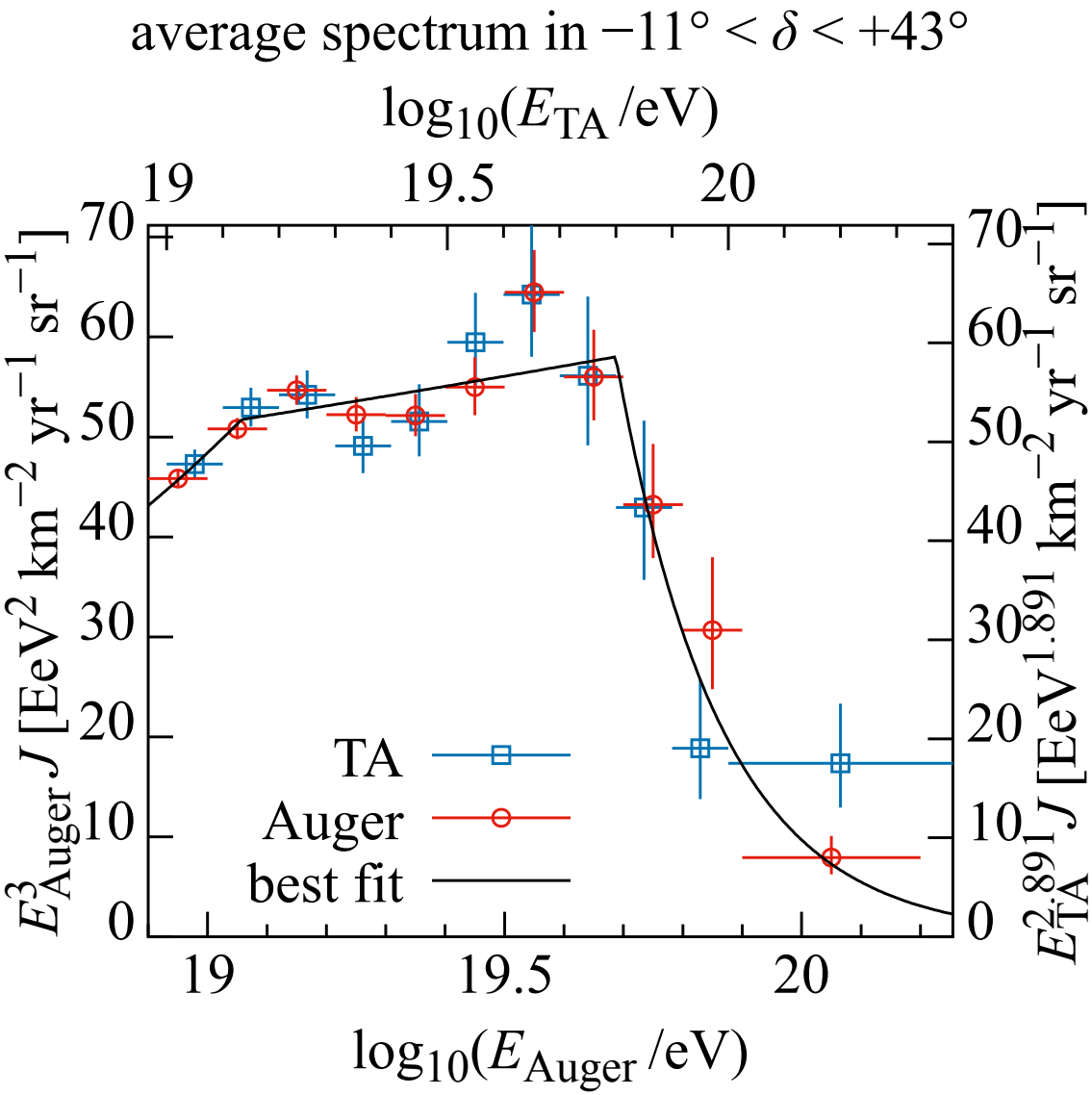

$\alpha = -0.159 \pm 0.012$

$\beta = 0.945 \pm 0.016$

$\chi^2/n = 20.7/14$

$p = 0.11$

$\mathbf{corr}(\ln(\alpha), \beta) = -0.17$

results

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- They have intuitive theoretical interpretations
- The amps $|\vec{d}|$ and $|\mathtt{Q}|$ are relatively stable wrt the GMF
- Only with a full-sky we can assume nothing about $a_{\ell m}$, $\ell > 2$

:: dipole and quadrupole ::

E_{Auger} [EeV] E_{TA} [EeV]	$[8.57, 16)$ $[10, 19.47)$	$[16, 32)$ $[19.47, 40.8)$	$[32, +\infty)$ $[40.8, +\infty)$
d_x [%]	$-0.2 \pm 1.1 \pm 0.0$	$+0.9 \pm 1.9 \pm 0.0$	$-4.4 \pm 3.7 \pm 0.1$
d_y [%]	$+5.0 \pm 1.1 \pm 0.0$	$+4.4 \pm 1.9 \pm 0.0$	$+10.0 \pm 3.5 \pm 0.0$
d_z [%]	$-3.0 \pm 1.3 \pm 1.2$	$-8.4 \pm 2.2 \pm 1.3$	$+3.3 \pm 4.4 \pm 3.5$
$Q_{xx} - Q_{yy}$ [%]	$-4.3 \pm 4.6 \pm 0.0$	$+12.9 \pm 8.1 \pm 0.0$	$+39.7 \pm 15.0 \pm 0.0$
Q_{xz} [%]	$-2.7 \pm 2.7 \pm 0.0$	$+4.1 \pm 4.7 \pm 0.0$	$+4.9 \pm 9.7 \pm 0.1$
Q_{yz} [%]	$-4.3 \pm 2.7 \pm 0.0$	$-8.3 \pm 4.6 \pm 0.1$	$+12.8 \pm 9.1 \pm 0.3$
Q_{zz} [%]	$+0.5 \pm 3.1 \pm 1.5$	$+4.5 \pm 5.4 \pm 1.5$	$+22.0 \pm 10.3 \pm 4.1$
Q_{xy} [%]	$+1.3 \pm 2.3 \pm 0.0$	$-0.6 \pm 4.0 \pm 0.1$	$+4.0 \pm 7.8 \pm 0.1$

Uncertainties: $\pm$ statistical $\pm$ cross-calibration. Statistical uncertainties are uncorrelated except $\rho(d_x, Q_{xz}) = \rho(d_y, Q_{yz}) = 0.45$ and $\rho(d_z, Q_{zz}) = 0.53$.

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E_{Auger} [EeV] E_{TA} [EeV]	$[8.53, 16)$ $[10, 19.49)$	$[16, 32)$ $[19.49, 40.5)$	$[32, +\infty)$ $[40.5, +\infty)$
d_x [%]	$-0.7 \pm 1.1 \pm 0.0$	$+1.6 \pm 2.0 \pm 0.0$	$-5.3 \pm 3.9 \pm 0.1$
d_y [%]	$+4.8 \pm 1.1 \pm 0.0$	$+3.9 \pm 1.9 \pm 0.1$	$+9.7 \pm 3.7 \pm 0.0$
d_z [%]	$-3.3 \pm 1.4 \pm 1.3$	$-6.0 \pm 2.4 \pm 1.3$	$+3.4 \pm 4.7 \pm 3.6$
$Q_{xx} - Q_{yy}$ [%]	$-5.1 \pm 4.8 \pm 0.0$	$+13.6 \pm 8.3 \pm 0.0$	$+42.7 \pm 15.6 \pm 0.1$
Q_{xz} [%]	$-3.9 \pm 2.9 \pm 0.1$	$+5.4 \pm 5.1 \pm 0.0$	$+4.9 \pm 10.5 \pm 0.1$
Q_{yz} [%]	$-4.9 \pm 2.9 \pm 0.0$	$-9.6 \pm 5.0 \pm 0.0$	$+11.9 \pm 9.8 \pm 0.2$
Q_{zz} [%]	$+0.5 \pm 3.3 \pm 1.7$	$+5.2 \pm 5.8 \pm 1.7$	$+19.5 \pm 11.0 \pm 4.6$
Q_{xy} [%]	$+2.2 \pm 2.4 \pm 0.0$	$+0.2 \pm 4.2 \pm 0.1$	$+4.4 \pm 8.1 \pm 0.1$

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ICRC2021

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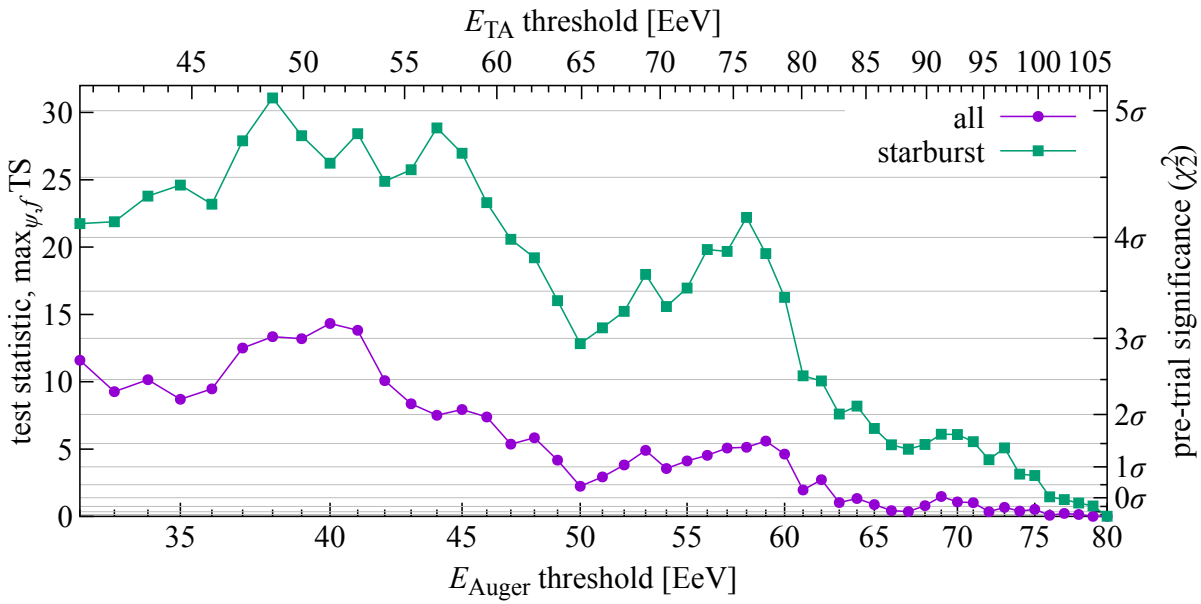
To reduce statistical penalties we do *not* model the coherent GMF, energy losses*, more than one source class at a time.

* Energy losses are expected to be small because SBGs are mostly nearby.

:: nearby galaxies ::

catalogue	$E_{\rm min}^{\rm (Auger)}$	$E_{\rm min}^{\rm (TA)}$	ψ [deg]	f [%]	TS	significance
all galaxies	40 EeV	51 EeV	29^{+11}_{-12}	41^{+29}_{-18}	14.3	$2.7\sigma_{\rm global}$
starburst	38 EeV	49 EeV	$15.1^{+4.6}_{-3.0}$	$12.1^{+4.5}_{-3.1}$	31.1	$4.6\sigma_{\rm global}$



UHECR2022

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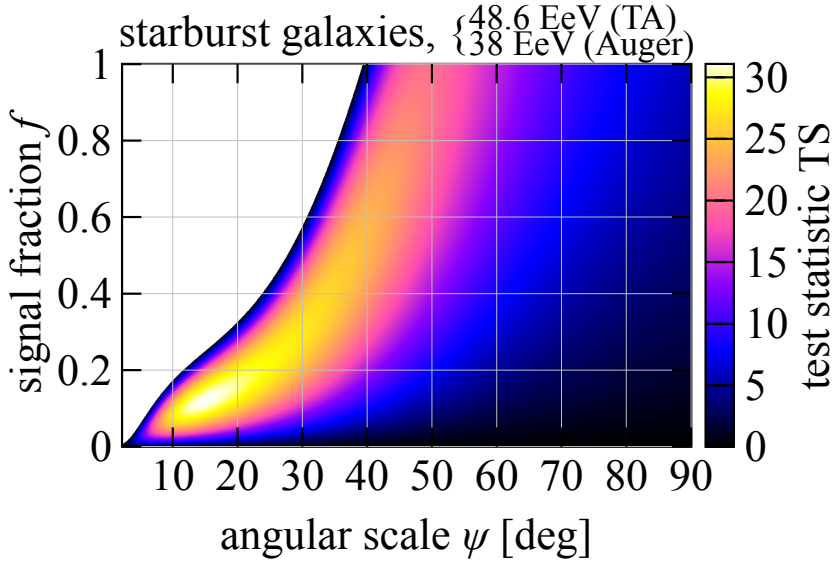

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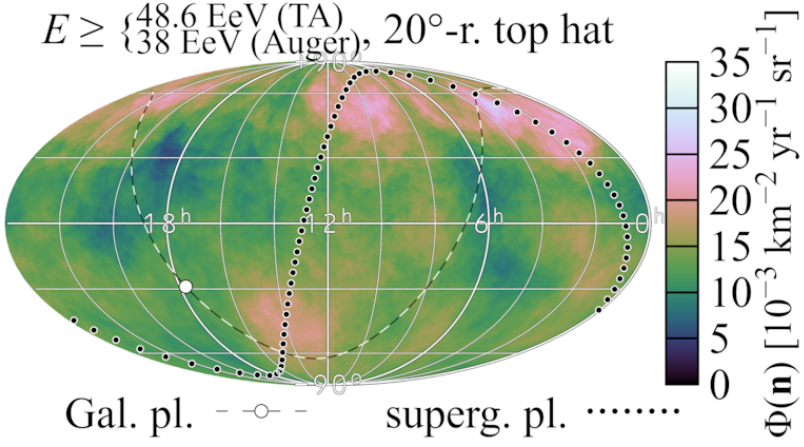

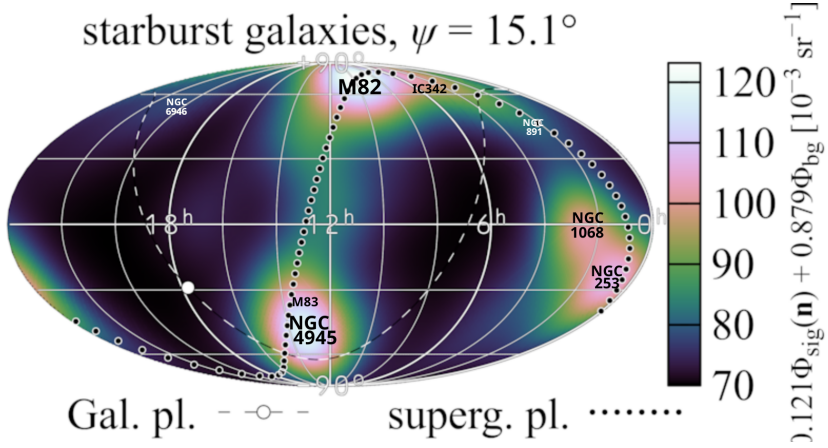

UHECR2022

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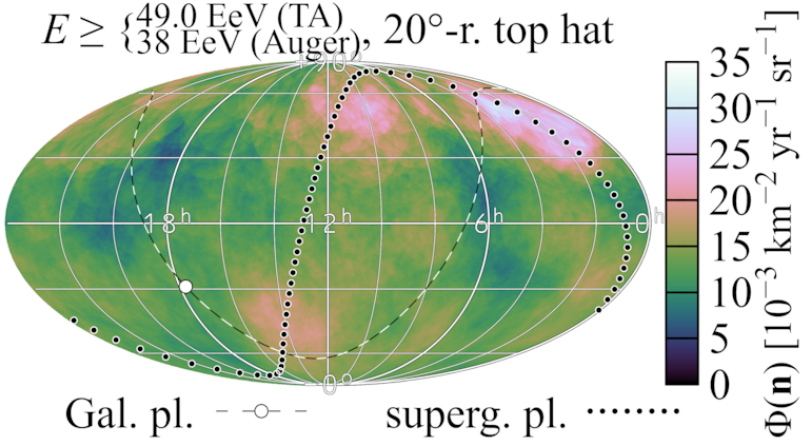

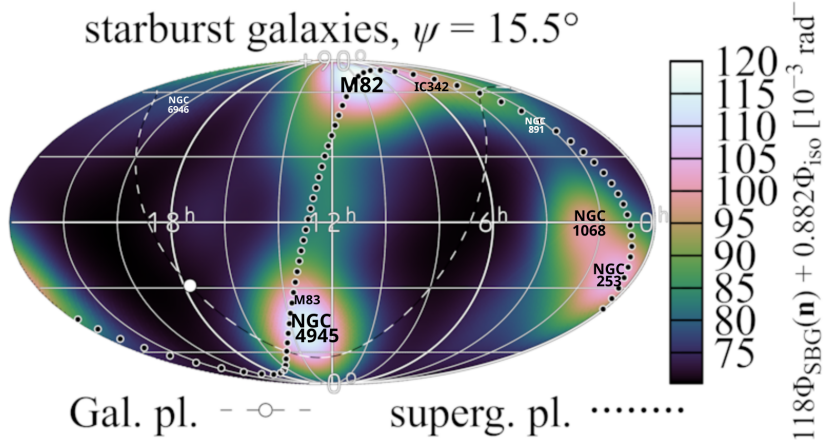

ICRC2021

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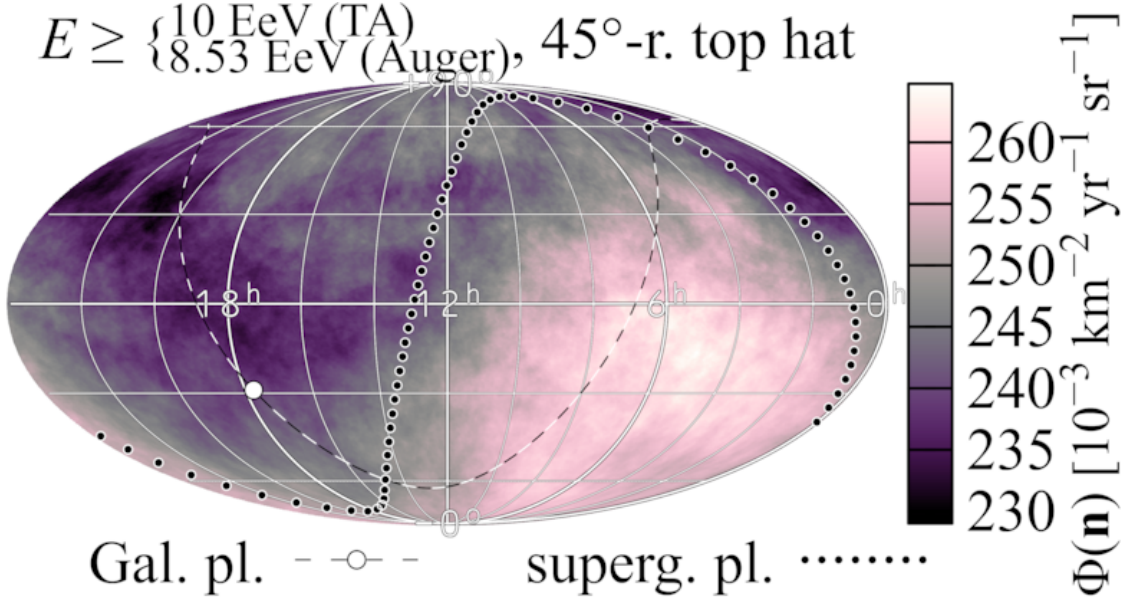
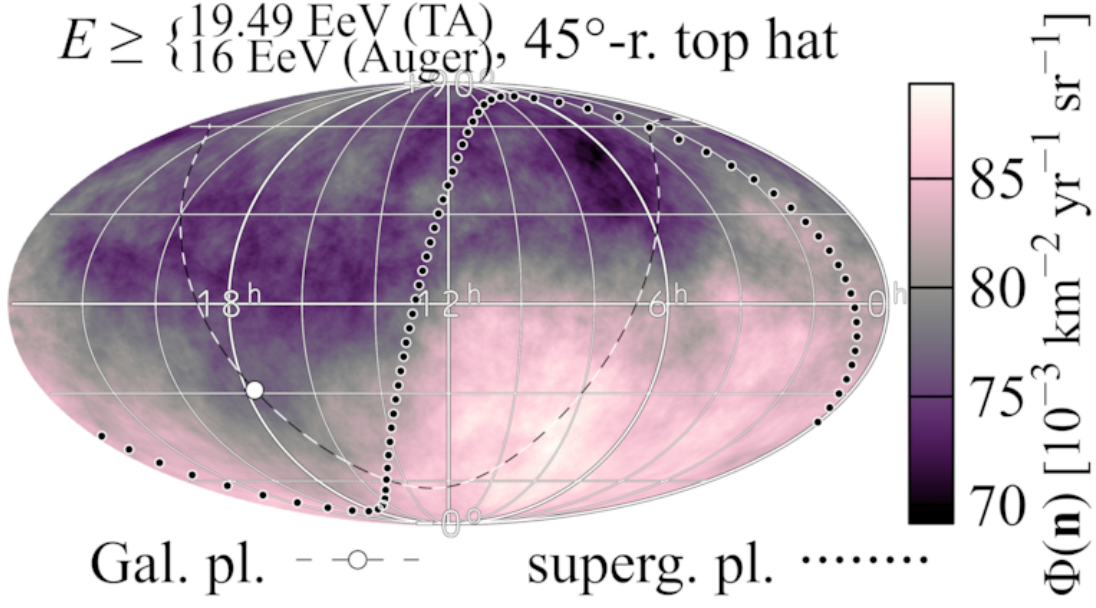
:: we need to keep running!!! ::


backups

:: sky maps ::


$E \geq \begin{cases} 10\ \text{EeV (TA)} \\ 8.53\ \text{EeV (Auger)} \end{cases}$, 45°-r. top hat
+90°
18h
12h
6h
0h
−90°
260
255
250
245
240
235
230
$\Phi(\mathbf{n})$ [10^{-3} km^{-2} yr^{-1} sr^{-1}]
Gal. pl.
superg. pl.

:: sky maps ::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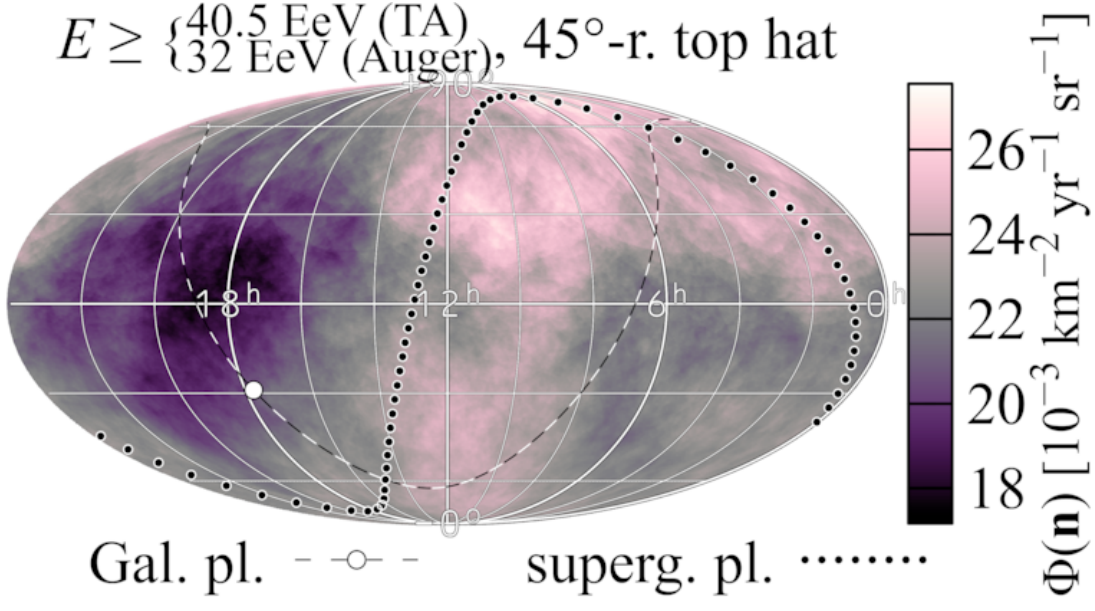
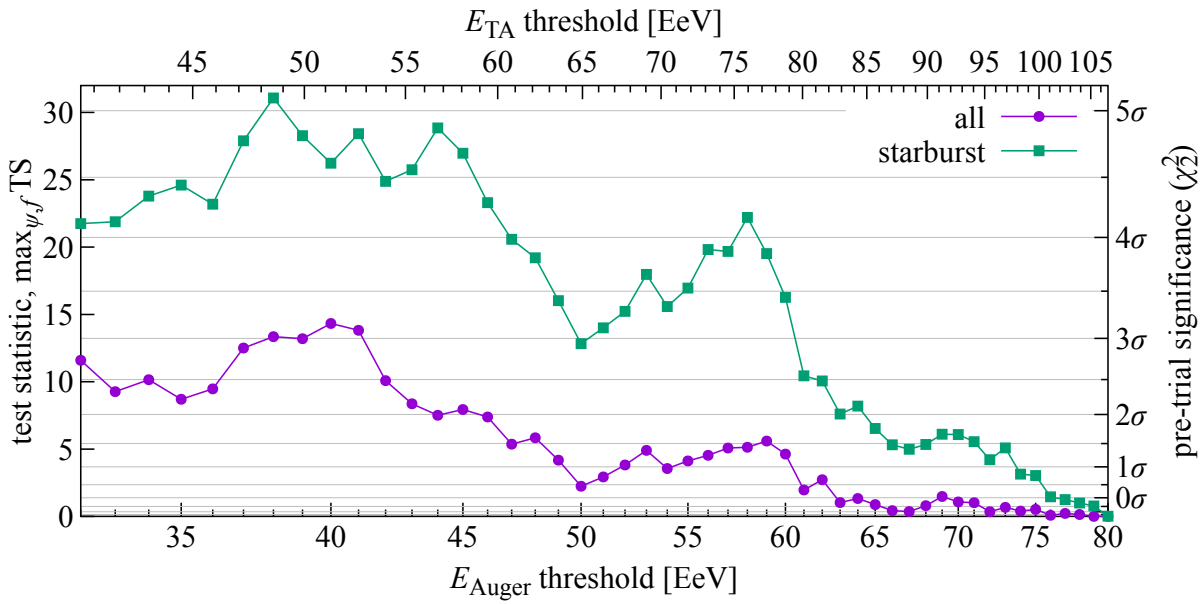
75
70
$\Phi(\mathbf{n})$ [10^{-3} km^{-2} yr^{-1} sr^{-1}]
Gal. pl.
superg. pl.

:: sky maps ::


$E \geq \begin{cases} 40.5 \text{ EeV (TA)} \\ 32 \text{ EeV (Auger)} \end{cases}$, 45°-r. top hat
+90°
18h
12h
6h
0h
−90°
26
24
22
20
18
$\Phi(\mathbf{n})$ [10^{-3} km^{-2} yr^{-1} sr^{-1}]
Gal. pl.
superg. pl.

:: nearby galaxies ::

catalogue	$E_{\rm min}^{\rm (Auger)}$	$E_{\rm min}^{\rm (TA)}$	ψ [deg]	f [%]	TS	significance
all galaxies	40 EeV	51 EeV	29^{+11}_{-12}	41^{+29}_{-18}	14.3	$2.7\sigma_{\rm global}$
starburst	38 EeV	49 EeV	$15.1^{+4.6}_{-3.0}$	$12.1^{+4.5}_{-3.1}$	31.1	$4.6\sigma_{\rm global}$



UHECR2022

:: nearby galaxies ::

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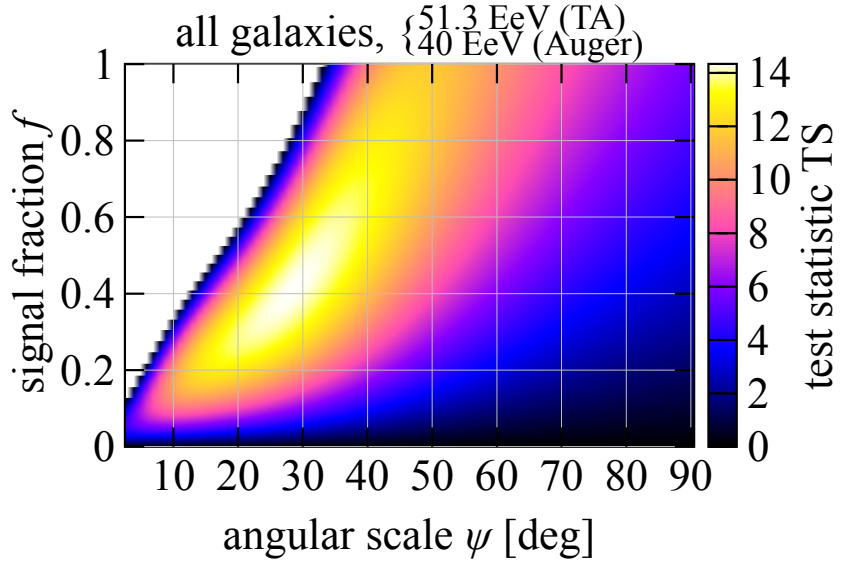

UHECR2022

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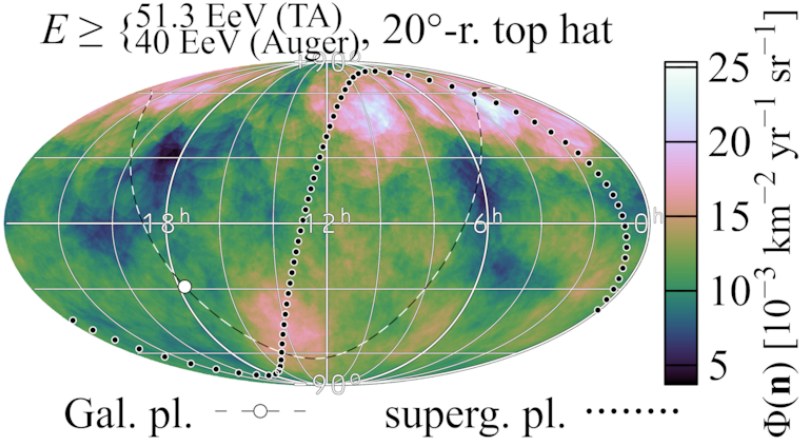
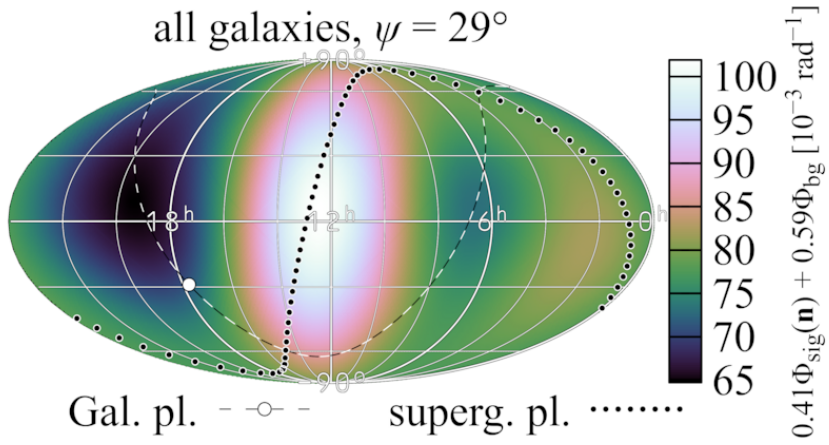
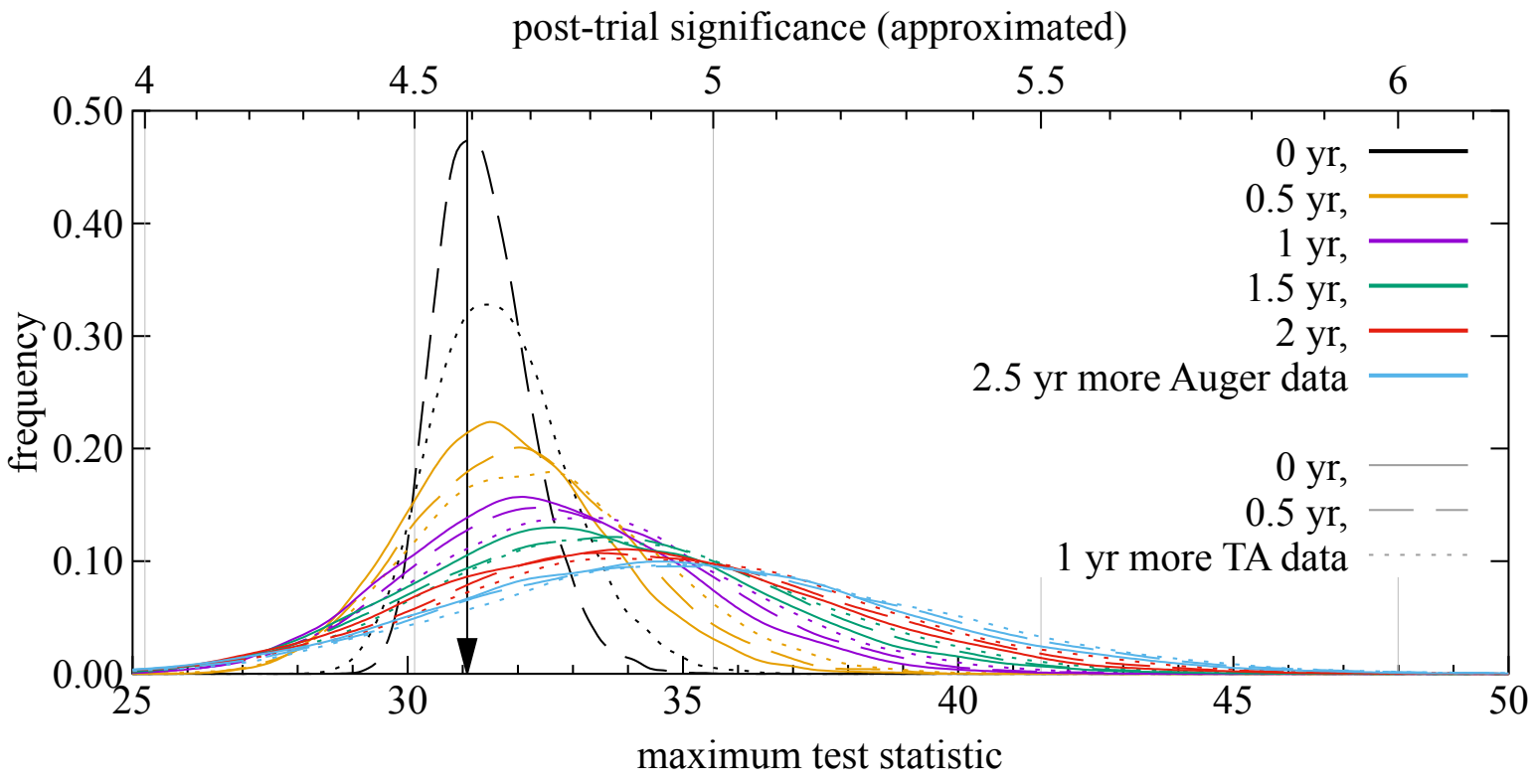




UHECR2022

:: predict ::



Most optimistic scenario: less than 50% chances of 5σ at ICRC2023