Search for neutrons from Galactic sources with the Pierre Auger Observatory

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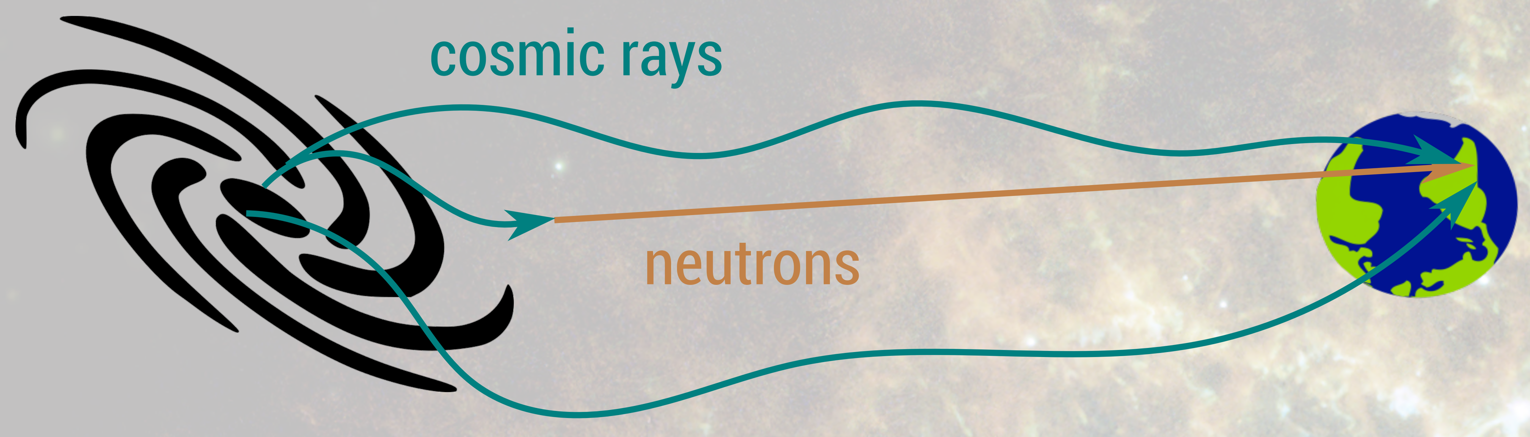
NEUTRONS



Neutrons can be produced in UHECR interactions near their sources

Neutrons decay after travelling a mean free path:

9.2 kpc x (E / EeV)

→ Use them to investigate galactic sources!

DETECTION TECHNIQUE

Showers induced by neutrons are indistinguishable from proton-induced ones

Neutrons are not deflected during propagation ⇒ look for excesses around the candidate source position, at scale of angular resolution of the Observatory

Given source position, assign weight to each event i based on:

1. Angular distance to source: ξ_i
2. Angular resolution: σ_i

$$w_i = \frac{1}{2\pi\sigma_i^2} \exp\left(-\frac{\xi_i^2}{2\sigma_i^2}\right)$$

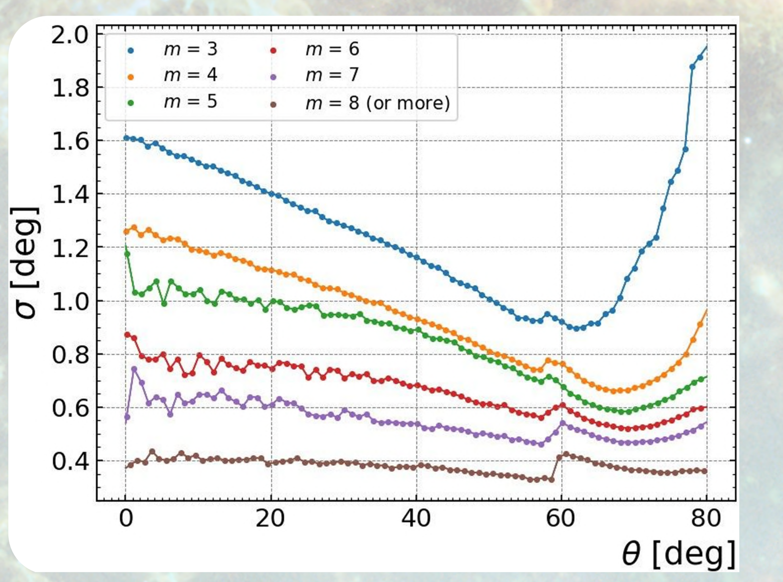
Compute the cosmic ray density at target's position and compare with density expected from 10 000 isotropic simulations

$$\rho = \sum_{i=0}^{N} w_i$$

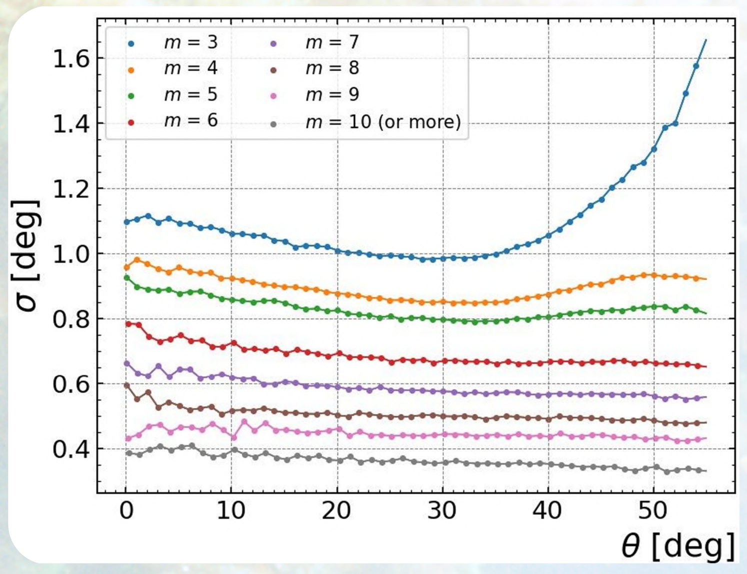
ANGULAR RESOLUTION

Parametrize angular resolution based on: **zenith angle** and on the **number of stations** used reconstruction

1 500 m array data set



750 m array data set



TARGET SETS

Selected 12 target sets ⇒ 888 sources with dec < 45°

122 sources at distance < 1 kpc and dec < 20° ⇒ can be used with data from 750 m surface detector array

- Millisecond pulsars
- γ-ray pulsars
- Low mass x-ray binaries
- High mass x-ray binaries
- γ TeV emitters: pulsar wind nebulae
- γ TeV emitters: other
- γ-ray TeV emitters: unidentified
- Microquasars
- Magnetars
- LHAASO PeVatrons
- Crab Nebula
- Galactic center

CONCLUSIONS

1. NO significant excess from any individual source

2. Performed combined analysis by multiplying p-values of all sources in each target set, weighting each source by their flux and distance ⇒ NO significant excess found!

3. Placed important and unique upper limits on purely hadronic emission of galactic sources at the highest energies

DATA SETS

1 500 m array data set

Events above 1 EeV

−90° ≤ dec ≤ 45°

Energy range	no. Events
1 EeV – 2 EeV	2,011,357
2 EeV – 3 EeV	382,809
≥ 3 EeV	267,440
≥ 1 EeV	2,661,606

750 m array data set

Events above 0.1 EeV

−90° ≤ dec ≤ 20°

Energy range	no. Events
0.1 EeV – 0.2 EeV	1,088,012
0.2 EeV – 0.3 EeV	249,642
≥ 0.3 EeV	167,758
≥ 0.1 EeV	1,505,412

RESULTS

Results for the most significant source in each target set

E-Flux Upper Limit computed assuming E^{-2} spectrum

E>1 EeV	RA [deg]	Dec [deg]	p-value	penalized p-value	flux UL [km^{-2} yr^{-1}]	E-flux UL [eV cm^{-2} s^{-1}]
msec pulsar	286.2	2.1	0.008	0.88	0.026	0.19
γ-ray pulsar	296.6	-54.0	5E-05	0.013	0.023	0.17
LMXB	237.0	-62.6	0.007	0.51	0.017	0.12
HMXB	308.1	41.0	0.014	0.57	0.133	0.97
Hess PWN	128.7	-45.6	0.007	0.18	0.016	0.12
Hess other	128.8	-45.2	0.022	0.63	0.014	0.11
Hess Unid.	305.0	40.8	0.007	0.31	0.145	1.06
Microquasars	308.1	41.0	0.014	0.19	0.131	0.95
Magnetars	249.0	-47.6	0.154	0.99	0.011	0.08
LHAASO	292.3	17.8	0.024	0.20	0.038	0.28
Crab	83.6	22.0	0.708	0.71	0.020	0.15
Galactic Center	266.4	-29.0	0.862	0.86	0.005	0.04

E>0.1 EeV	RA [deg]	Dec [deg]	p-value	penalized p-value	flux UL [km^{-2} yr^{-1}]	E-flux UL [eV cm^{-2} s^{-1}]
msec pulsar	140.5	-52.0	0.043	0.66	1.71	12.5
gamma ray pulsar	284.4	1.7	0.056	1.00	2.67	19.5
HMXB	116.8	-53.3	0.009	0.07	2.06	15.1
Hess PWN	277.9	-9.9	0.122	0.48	1.84	13.4
Hess other	288.2	10.2	0.003	0.04	5.50	40.2
Magnetars	274.7	-16.0	0.134	0.44	1.62	11.8

Take aways:

NO significant excess found for any source!

Most significant target: γ-ray pulsar J1946-5403