Search for Anisotropy
with the Pierre Auger Observatory

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for the Pierre Auger Collaboration

EPS Manchester 2007

PIERRE AUGER OBSERVATORY

III. Physikalisches Institut A
RWTH AACHEN UNIVERSITY

Outline

Introduction Auger

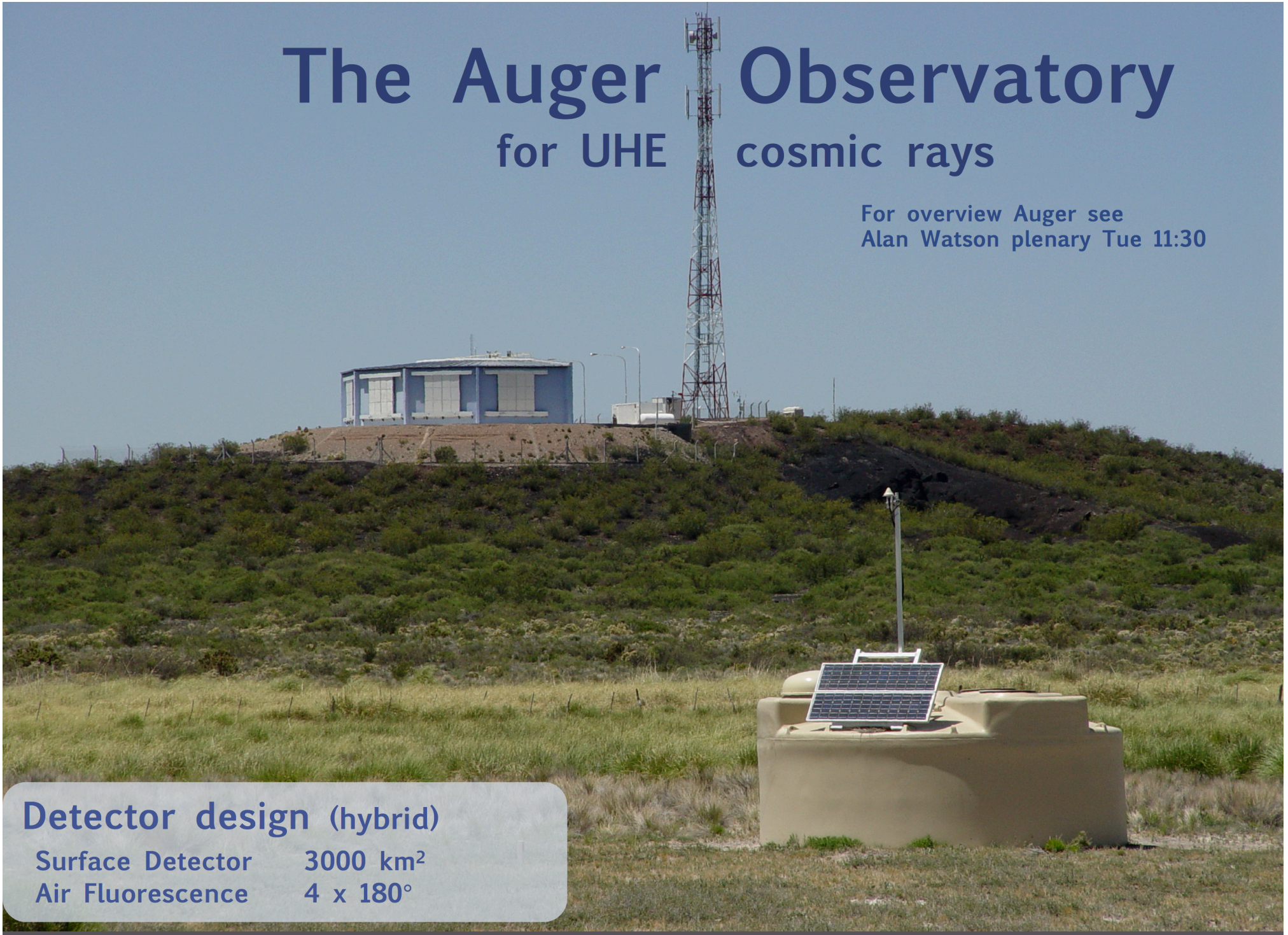
Anisotropy Search Strategies

Status of Observation

Summary

The Auger Observatory
for UHE cosmic rays

For overview Auger see
Alan Watson plenary Tue 11:30



Detector design (hybrid)

Surface Detector	3000 km^2
Air Fluorescence	4 x 180°

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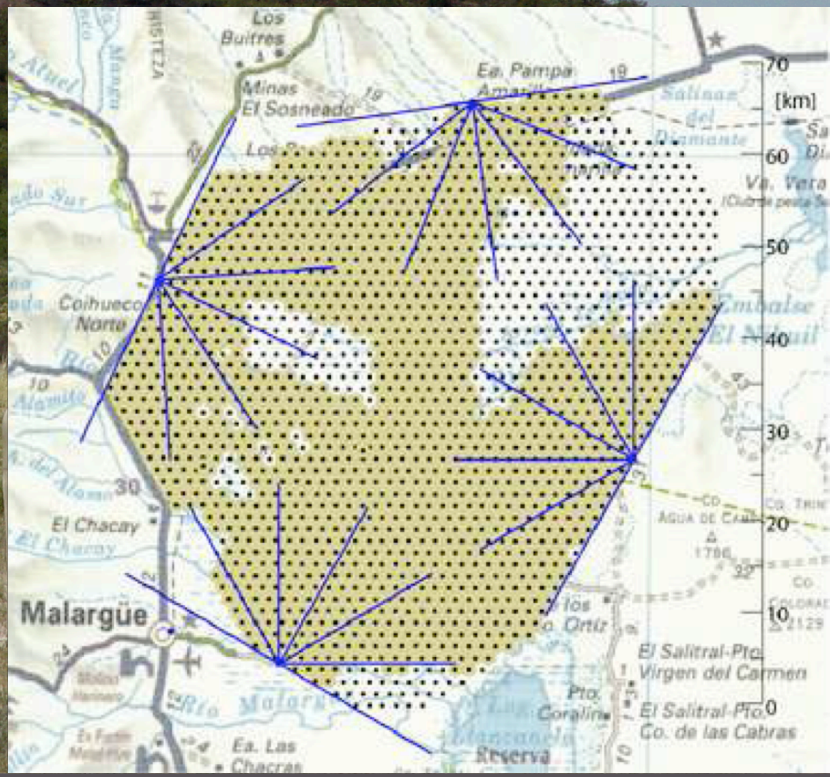

Status of construction

Surface Detector	85% / 1600 tanks
Air Fluorescence	24 / 24 cams

Detector design (hybrid)

Surface Detector	3000 km^2
Air Fluorescence	4 x 180°

The Auger Observatory
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Data set (as of March 2007)

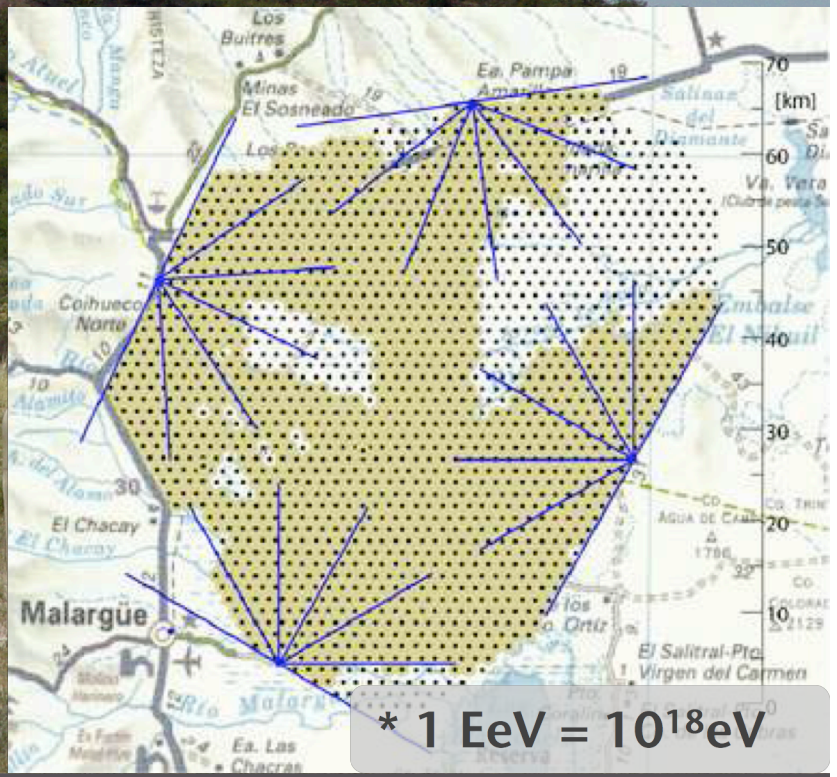
> 4 x AGASA exposure
> 1.700 events E > 10 EeV
> 60 events E > 40 EeV

Status of construction

Surface Detector 85% / 1600 tanks
Air Fluorescence 24 / 24 cams

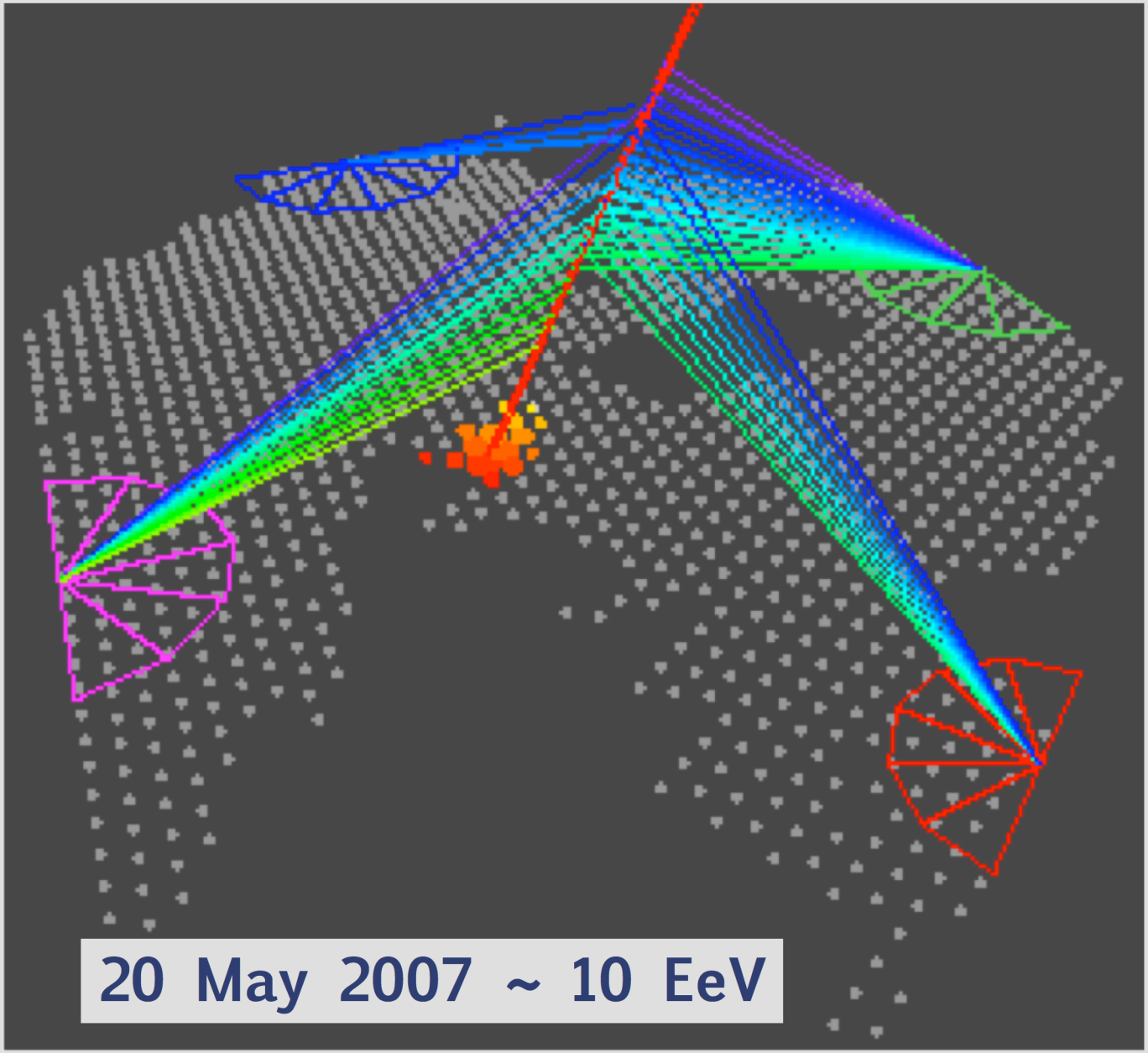
Detector design (hybrid)

Surface Detector 3000 km²
Air Fluorescence 4 x 180°



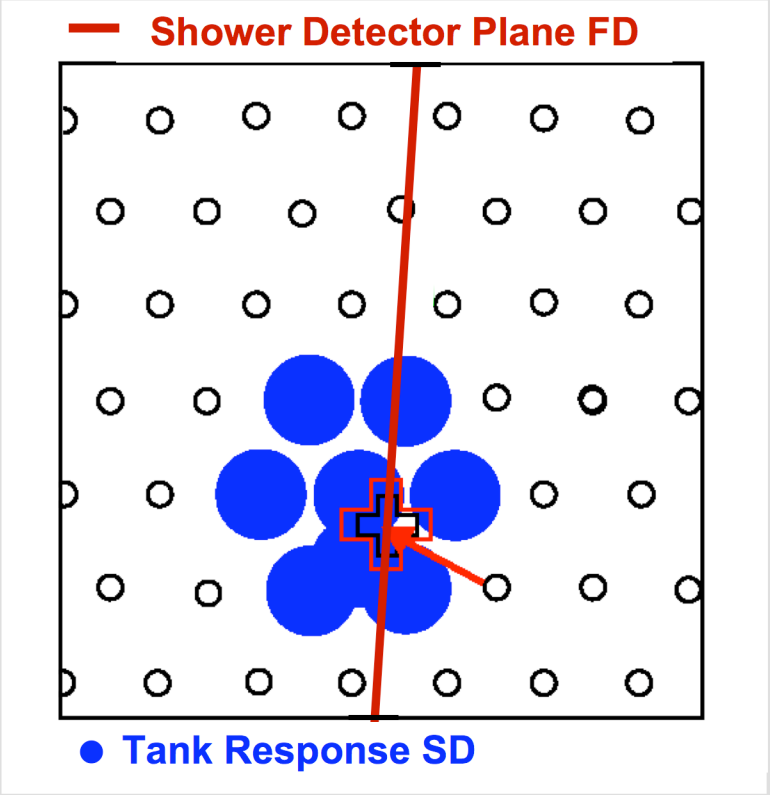
* 1 EeV = 10^{18}eV

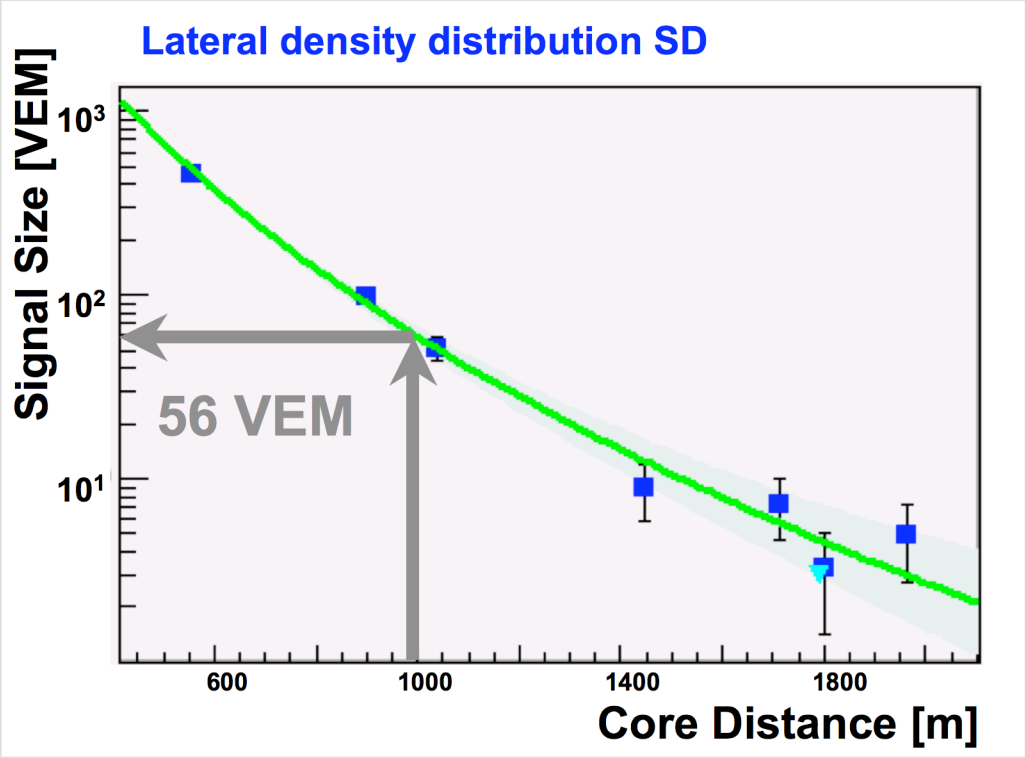
A ‘hybrid’ event



Event Reconstruction

Zenith angle ~ 30°, Energy ~ 10 EeV





Shower direction from arrival times of shower front in tanks

Resolution:* ≈ 2-3° @ 1 EeV

≈ 1° @ 10 EeV

Energy estimate from signal size @ 1000m from core

Calibration with hybrid events.

* 68% contour

Astrophysical Constraints

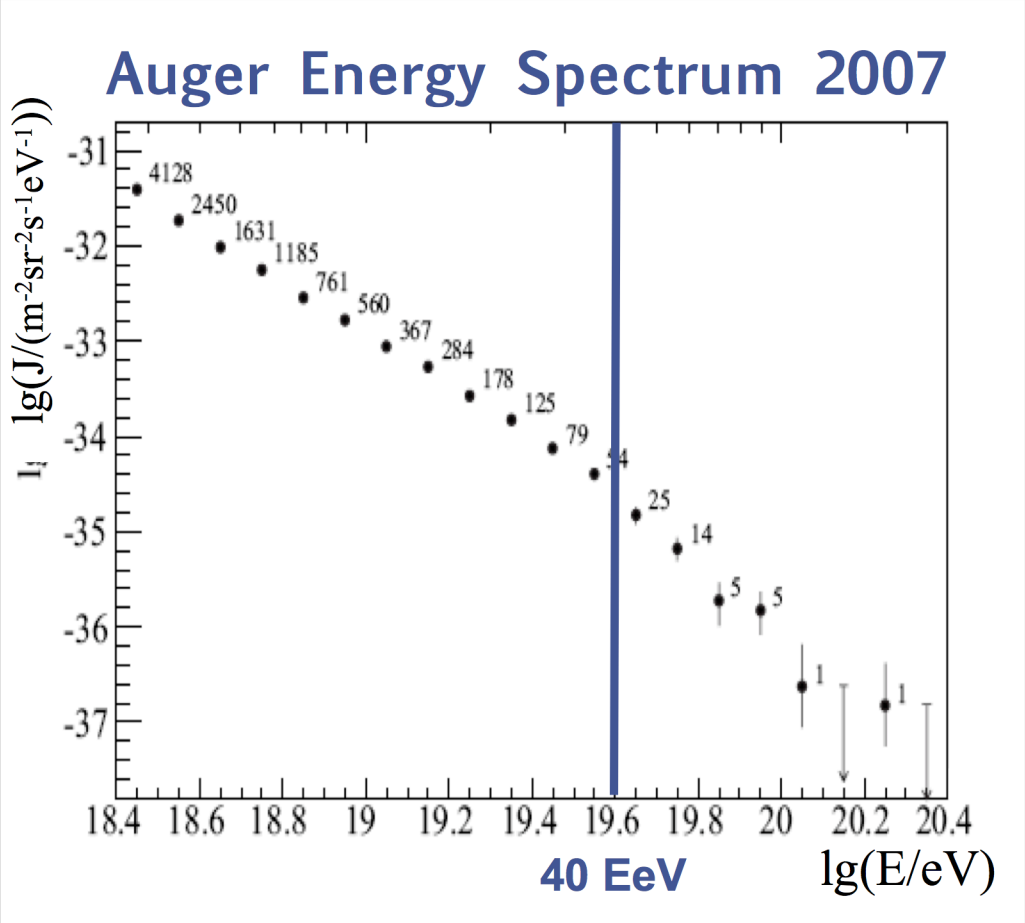
1 EeV = 10^{18} eV

- **Magnetic Deflection**
  - intergalactic $O(2\text{-}3)^\circ$ 40 EeV 100 Mpc
  - galactic $O(1\text{-}2)^\circ$ 40 EeV off disc

  ➜ pointing improves with E
- **Steep spectrum ~ $E^{-2.6}$**

  ➜ statistics falls with E

Anisotropy searches are very sensitive to energy selection.



➜ Charged Particle Searches E > ~ 40 EeV

➜ Neutral Particle Searches E = 0.1 ... 10 EeV

Anisotropy Searches

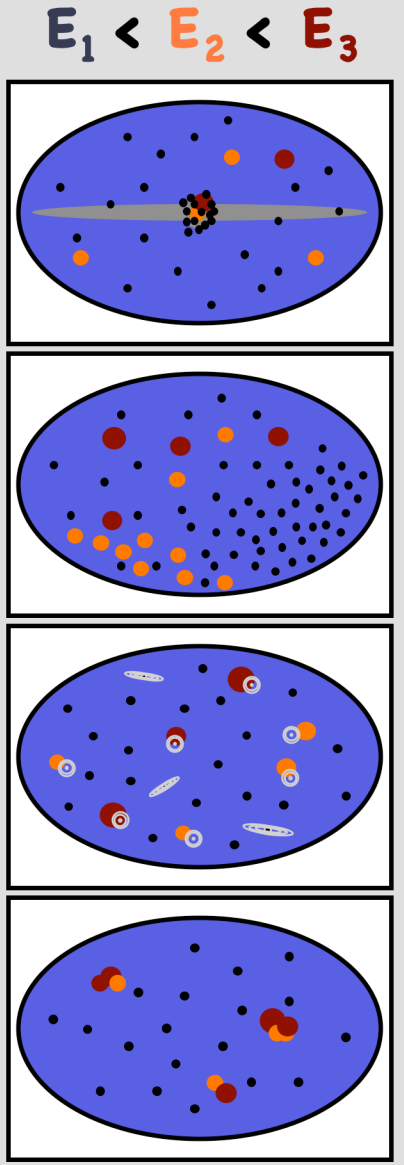
Motivation: search for source of
Ultra High Energy Cosmic Rays

1 Galactic Center

2 Multipole Search
(Large scale anisotropy)

3 Correlation BL Lacs

4 Cluster Search
(Autocorrelation)



Exposure estimation

E < 3 EeV

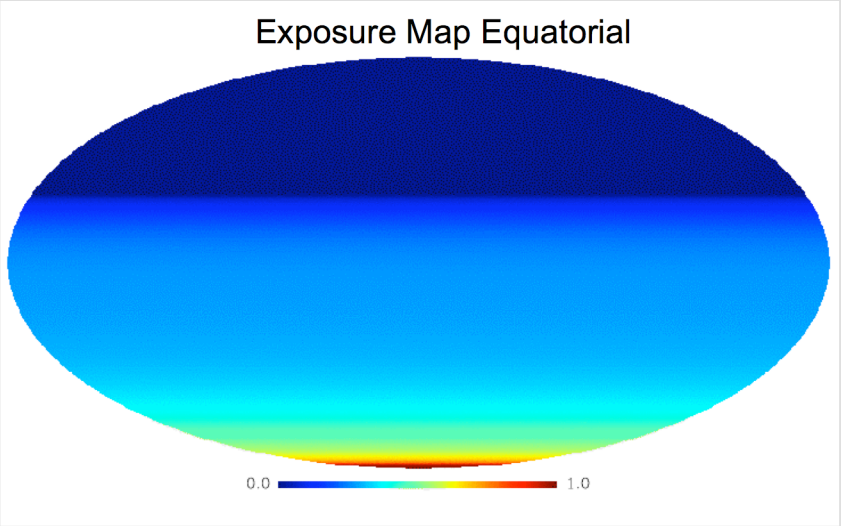
- derive zenith distr. from data
- use detector symmetry in azimuth
- overlay complete siderial days

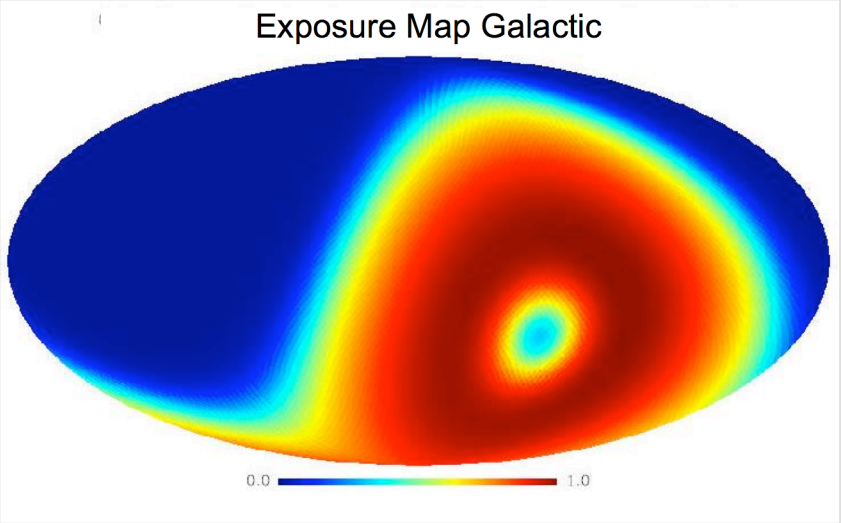
➜ smooth exposure estimate

E > 3 EeV

- assume saturated acceptance

➜ proceed as above



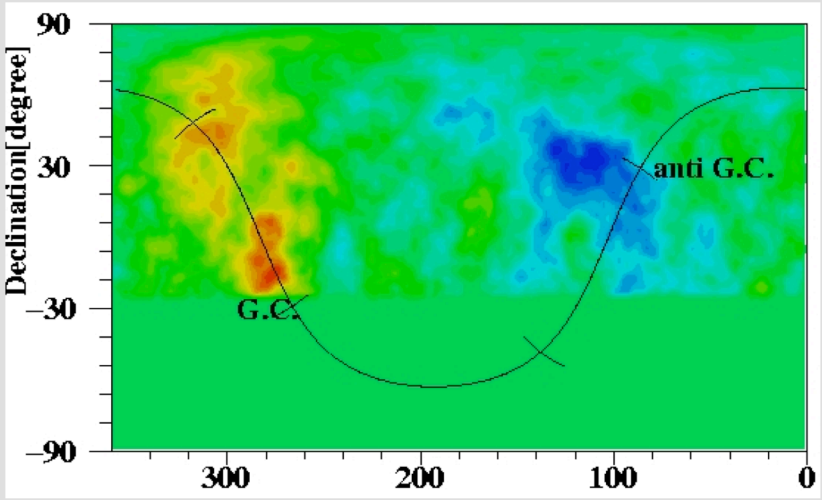


1 The Galactic Center

previous observations

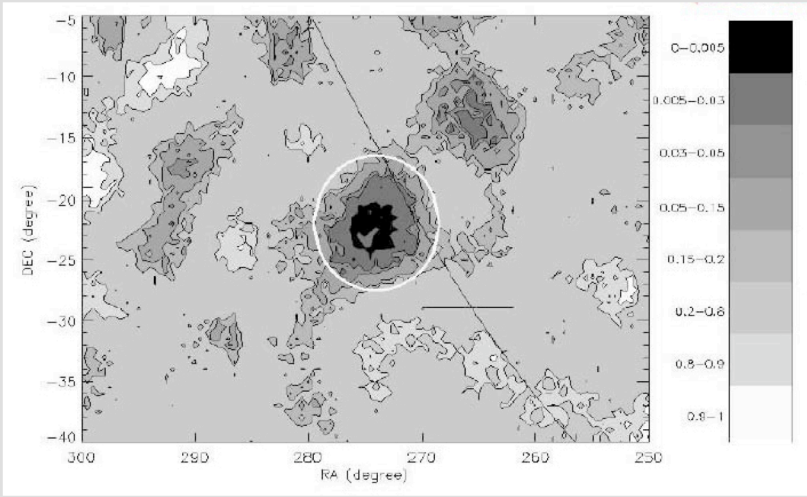
AGASA: (Hayashida et. al. 1999)

Search bin 20° radius @ (280°,-17°)
Energy 1 - 2.5 EeV
Observed 506/413.3 events (4.5 σ)



SUGAR: (Bellido et. al. 2001)

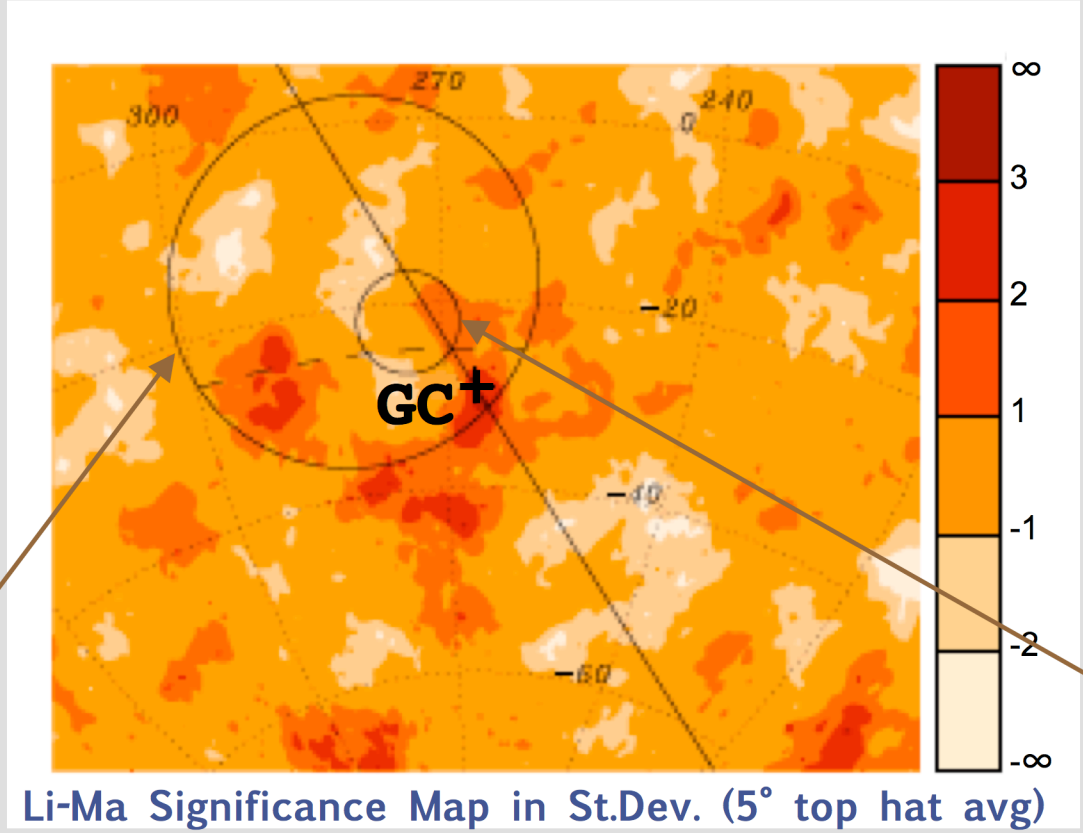
Search bin 5.5° radius @ (274°,-12°)
Energy 0.8 - 3.2 EeV
Observed 21.8/11.8 events (2.9 σ)



H.E.S.S: gamma ray observation Sgr A

1 The Galactic Center

Auger Data 2004-2007



Li-Ma Significance Map in St.Dev. (5° top hat avg)

Auger with 4x exposure of AGASA

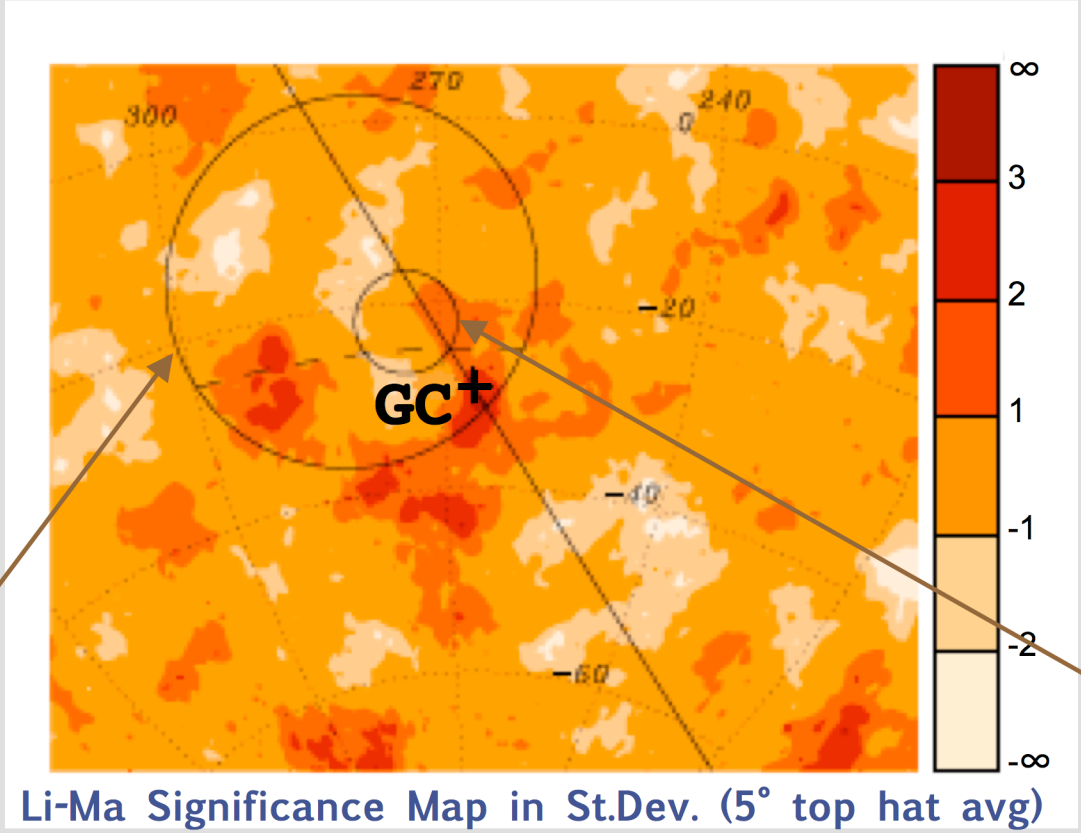
2116/2159.5 events (0.98 ± 0.02)

Auger with 2x exposure of SUGAR

286/289.7 events (0.98 ± 0.06)

1 The Galactic Center

Auger Data 2004-2007



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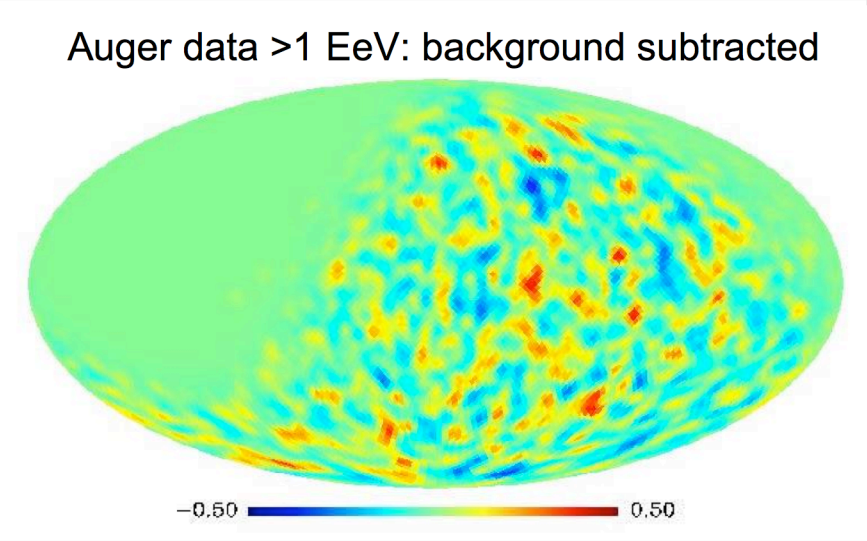
Auger with 2x exposure of SUGAR

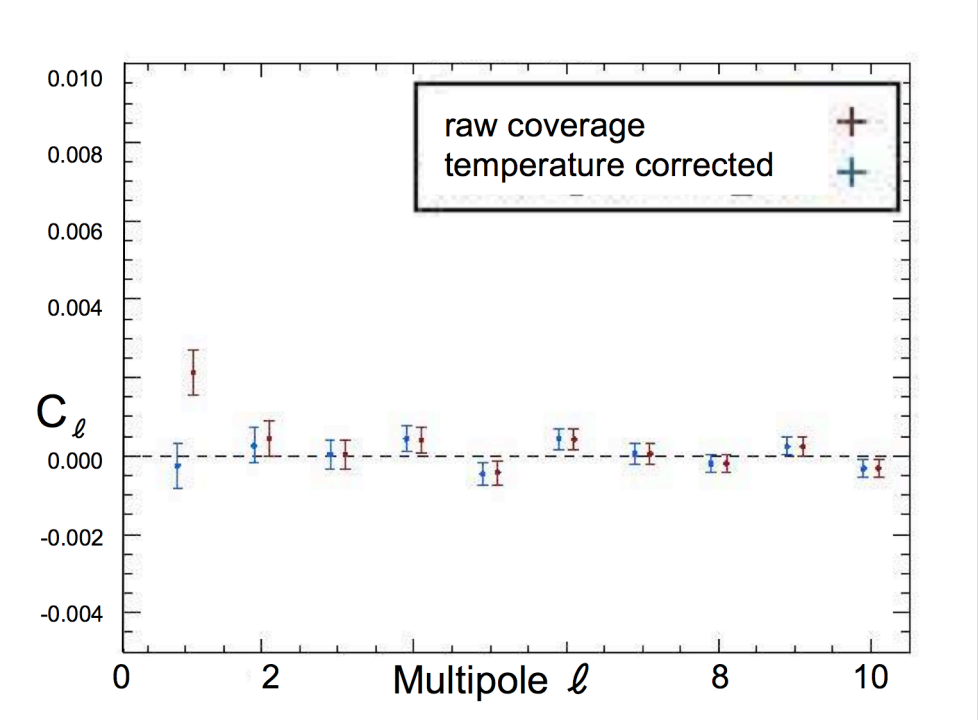
286/289.7 events (0.98 ± 0.06)

No evidence for observation of Galactic Center.

2 Multipole Analysis



Develop fluctuations on spherical harmonic

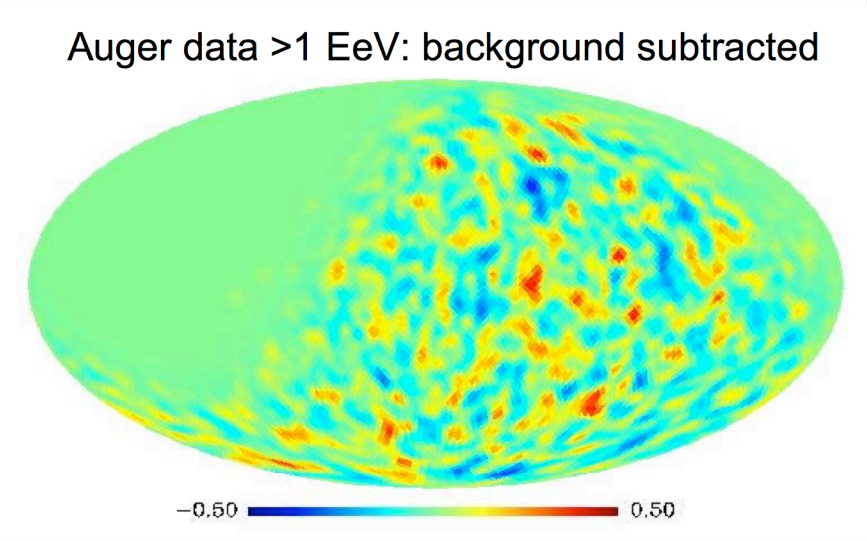


Derived C_ℓ :

Before and after correction for atmospheric temperature

Dipole (1-3 EeV): $C_1 < 0.7\%$

2 Multipole Analysis



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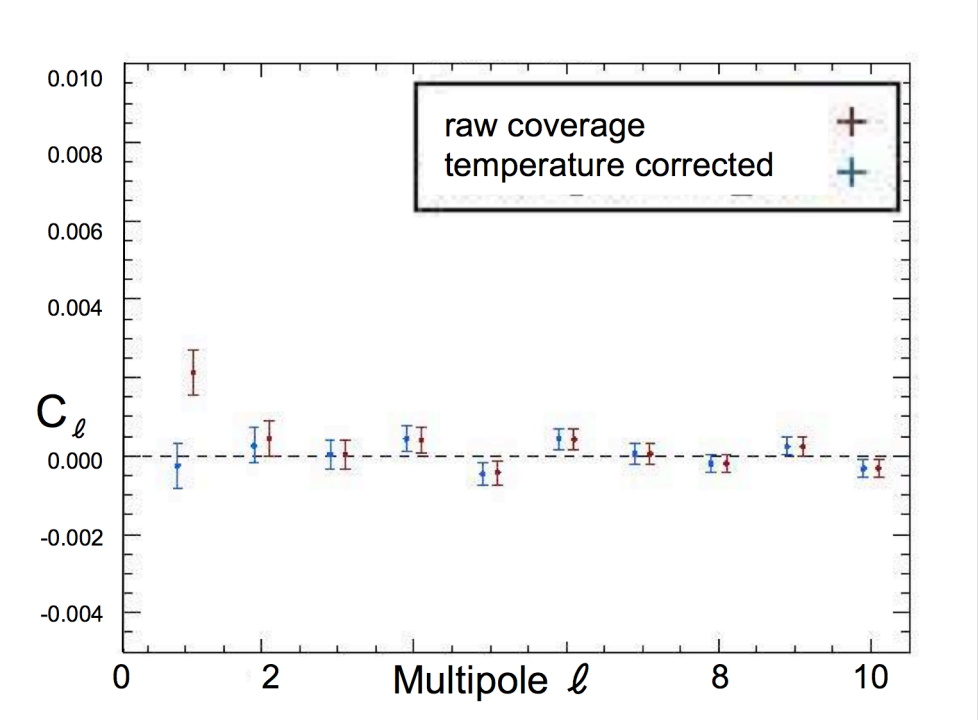

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Before and after correction for atmospheric temperature

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No evidence for dipole or multipole.

3 Correlation with BL Lacertae*

Previously claimed based on
Data from AGASA, Yakutsk and HiRes E > 10 EeV

BL Lacs from Catalogue of Quasars and AGN, Veron-Cetty & Veron

Test	BL Lacs	Selection	Auger field of view
A	22	m<18 distant radio emitters (9th ed.)	8
B	157	m<18 (10th ed.)	76
C	14	γ-bright	3
D	204	Confirmed BL and highly polarized sources	106

* Blazar with jet pointing towards Earth

3 Correlation with BL Lacertae*

Test with data taken by Auger
Largest Data set for E > 10 EeV

BL Lacs from Catalogue of Quasars and AGN, Veron-Cetty & Veron

Test	BL Lacs	Events	Correlations		Probability
			observed	expected	
A	8	267	1	1.0	0.63
B	76	62	2	2.5	0.71
C	3	267	1	0.5	0.41
D	106	1672	11	12.1	0.66

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No evidence for correlation with BL Lacs.

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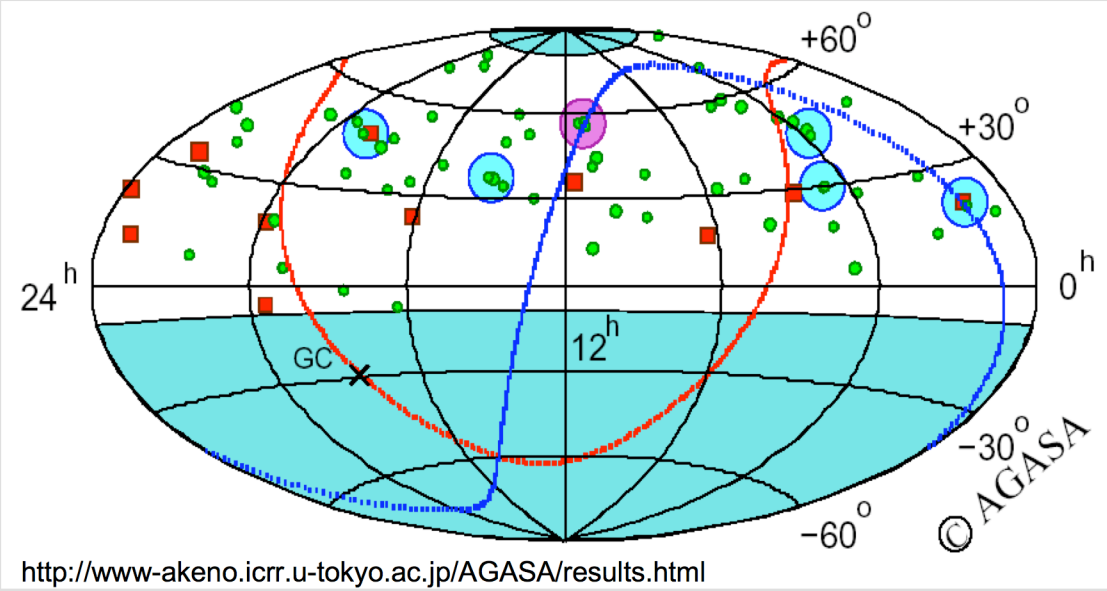
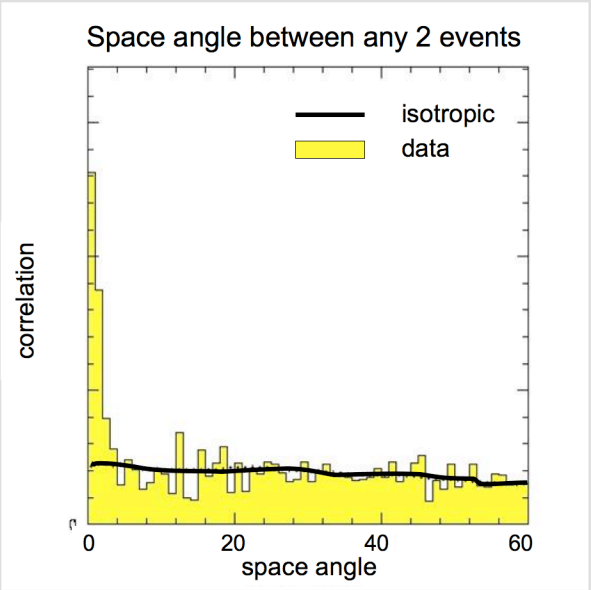
4 Cluster Search

Previously observed by AGASA
E > 40 EeV, angular separation 2.5°





40 – 100 EeV > 100 EeV

Doublet Triplet

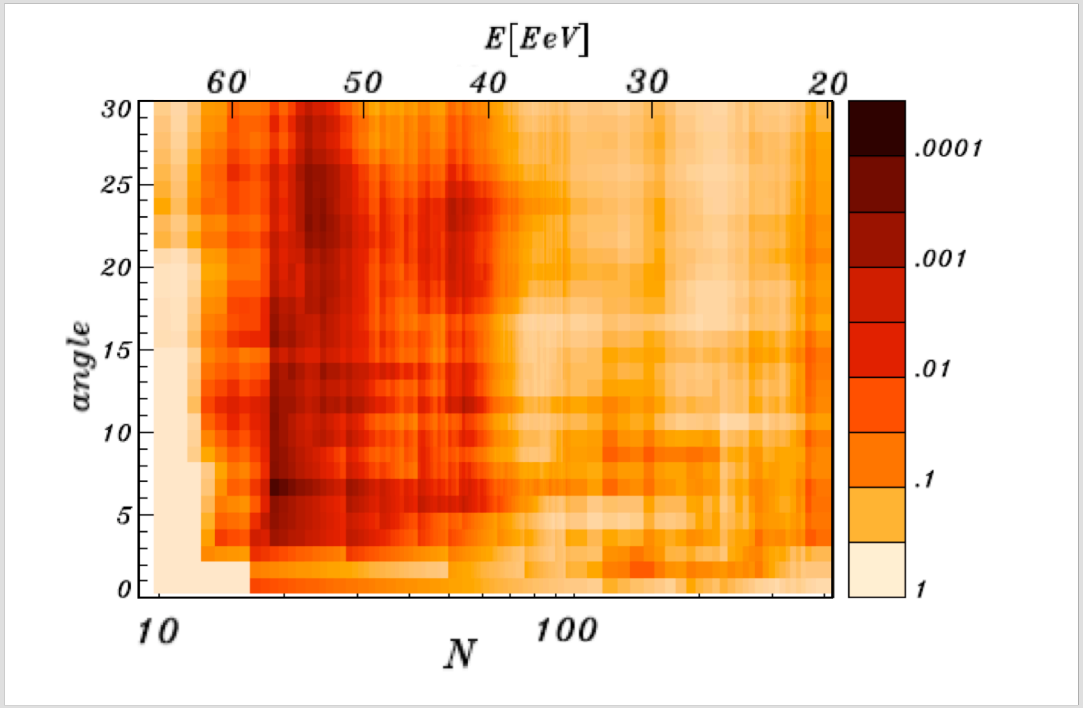
Takeda et. al. ApJ 1999: Probability* < 1%

* Probability for a single search

4 Cluster Search

Test with Auger Data E > 20 EeV

Cut replaced by scan over energy and separation angle.



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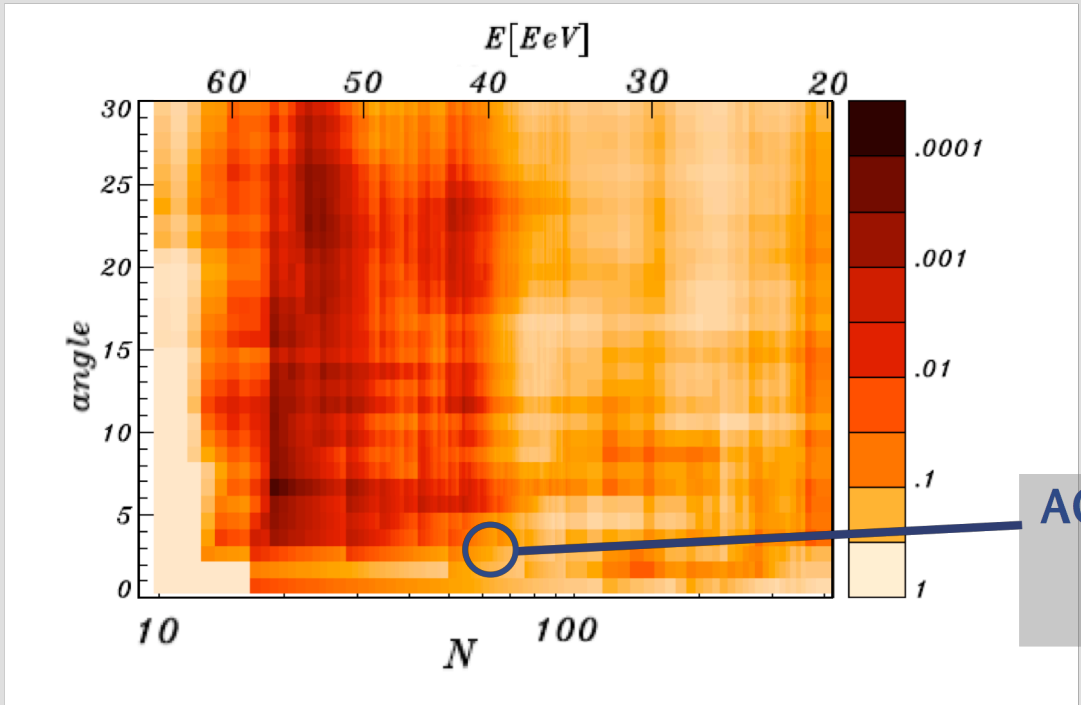

AGASA type search*
E> 40 EeV
Angular bin 2.5°

* Other hemisphere, other period

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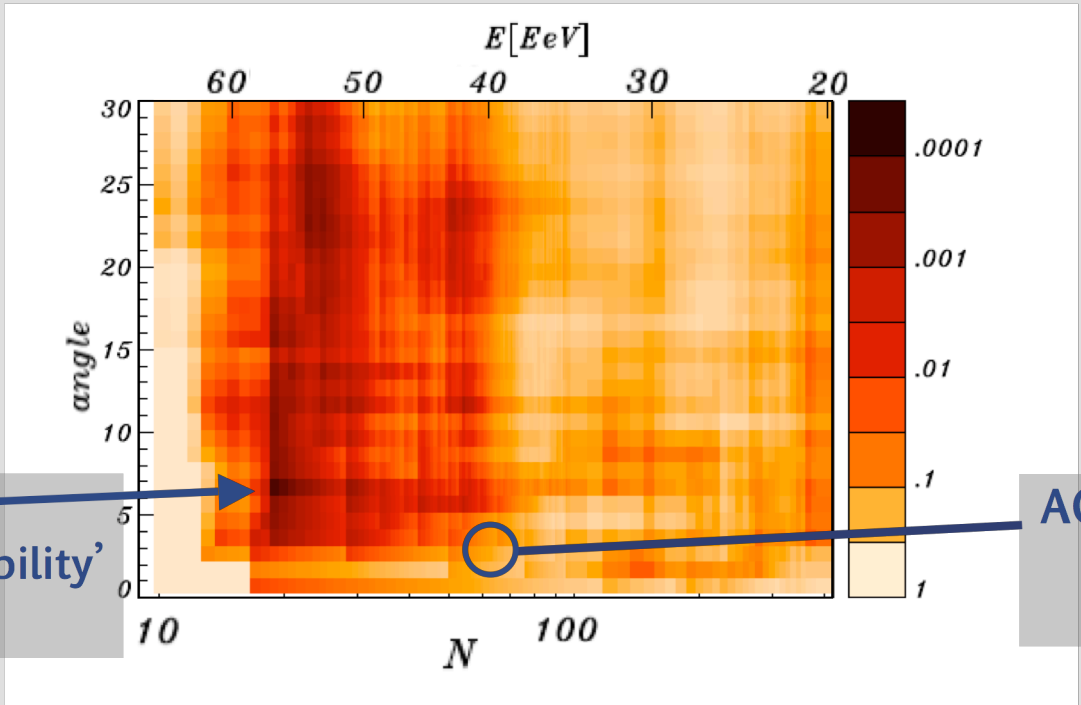

Minimum for 'Single search probability'
$P_{single} < 10^{-4}$

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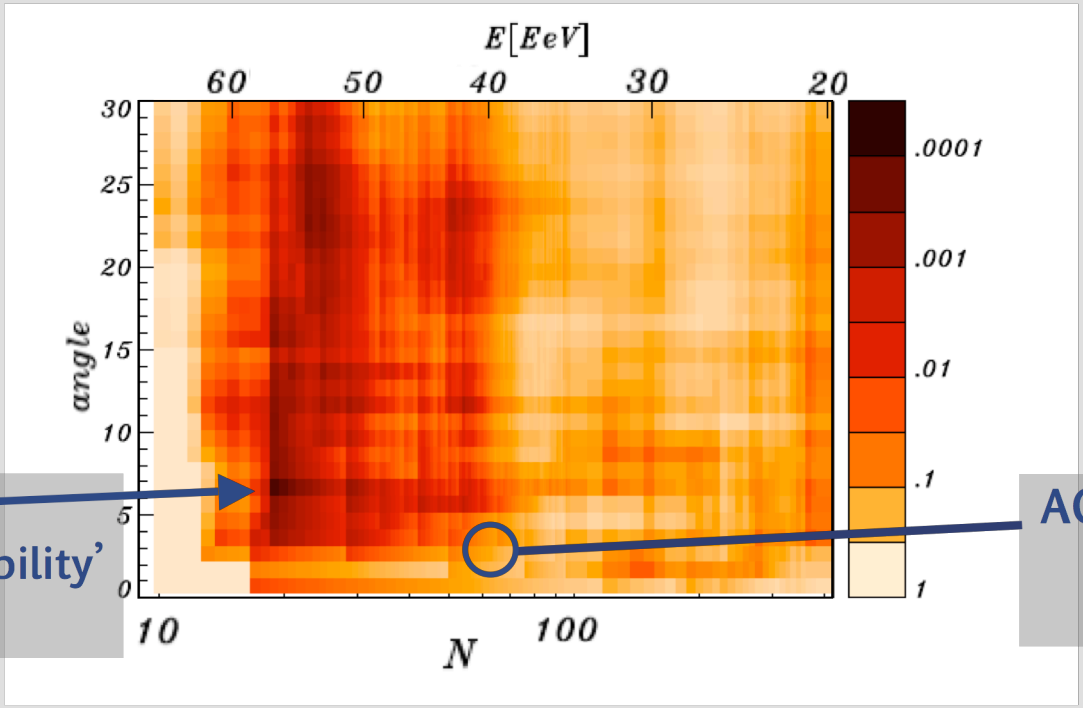

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Chance probability of similar or lower value with a scan: $P_{scan} \approx 2\%$

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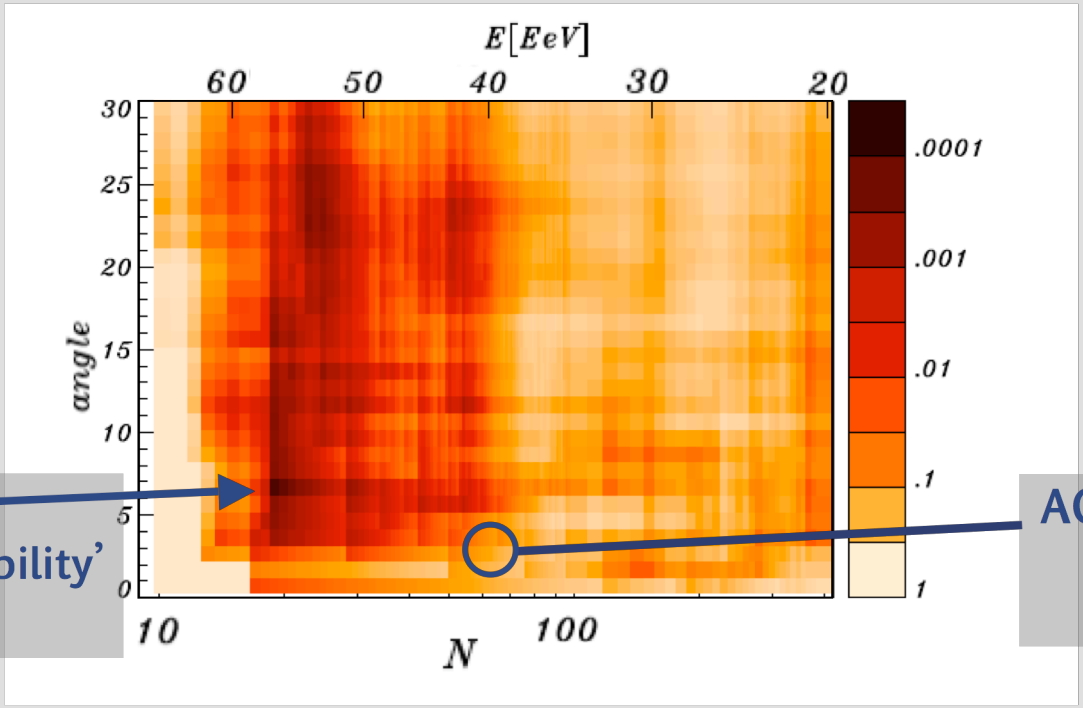

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Angular bin 2.5°

Chance probability of similar or lower value with a scan: $P_{scan} \approx 2\%$

No significant observation of clusters.

* Other hemisphere, other period

Summary

- Data set Jan 2004 - Mar 2007
  - > 1.7k events > 10 EeV
  - > 60 events > 40 EeV
- Auger angular resolution:
  - ~ 1° for surface detector data E > 3 EeV
- Anisotropy searches:
  1. Galactic Center: no significant emission
  2. Large Scale Anisotropy no structure
  3. Correlation with BL Lacs no correlation
  4. Cluster Search no clustering ($P_{min} \approx 2\%$)

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Auger will double statistics within a year!

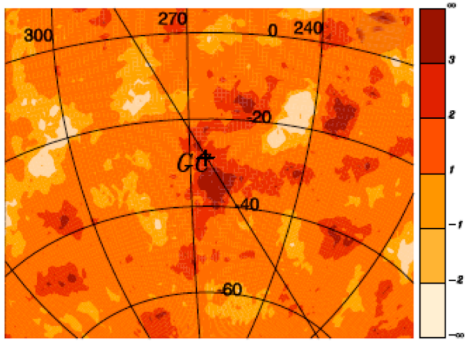
1 The Galactic Center

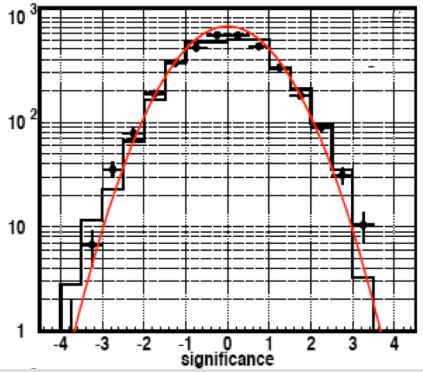
Auger Data 2007

C - Neutron rich sample:

1 EeV < E < 10 EeV

➜ limit neutron flux: < 2% access
➜ L_{GC}< 1.25 x 10^34 erg/s

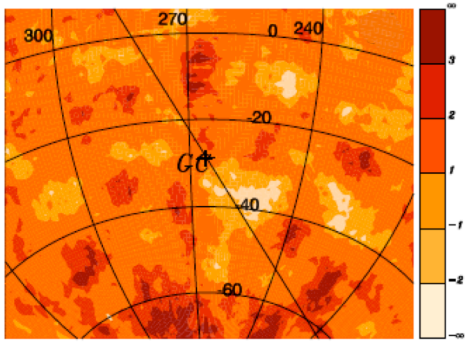


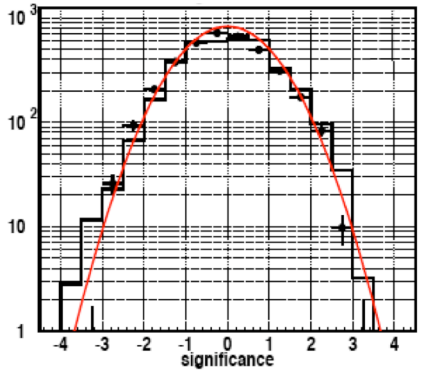


D - Gamma rich sample:

0.1 EeV < E < 1 EeV

➜ H.E.S.S. observation 0.0001 EeV
➜ no limit - photon acceptance differs





Significance Map in St.Dev. (5° top hat avg)

E - Point source search

1.2° 16.9 / 17.0 0.95 ± 0.17

No evidence for observation of Galactic Center.

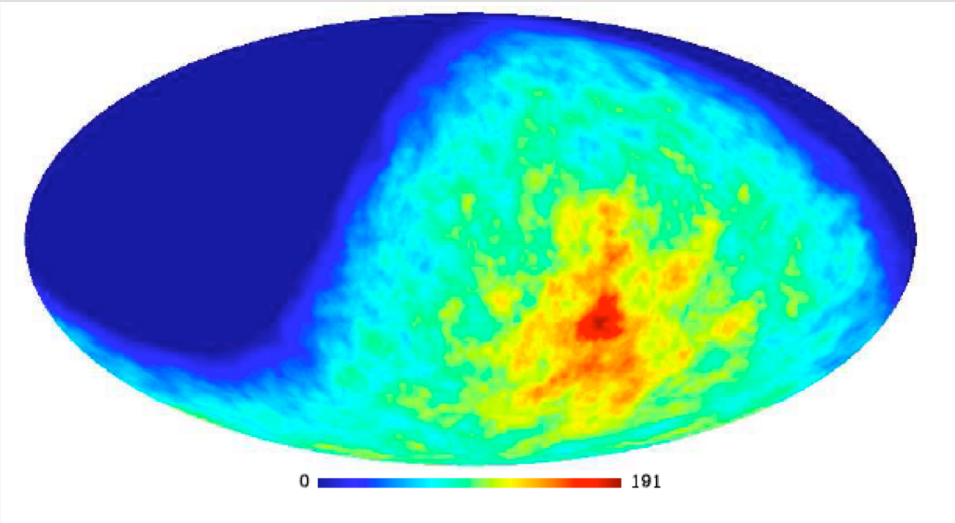
2 Large Scale Anisotropy

Previously observed by AGASA

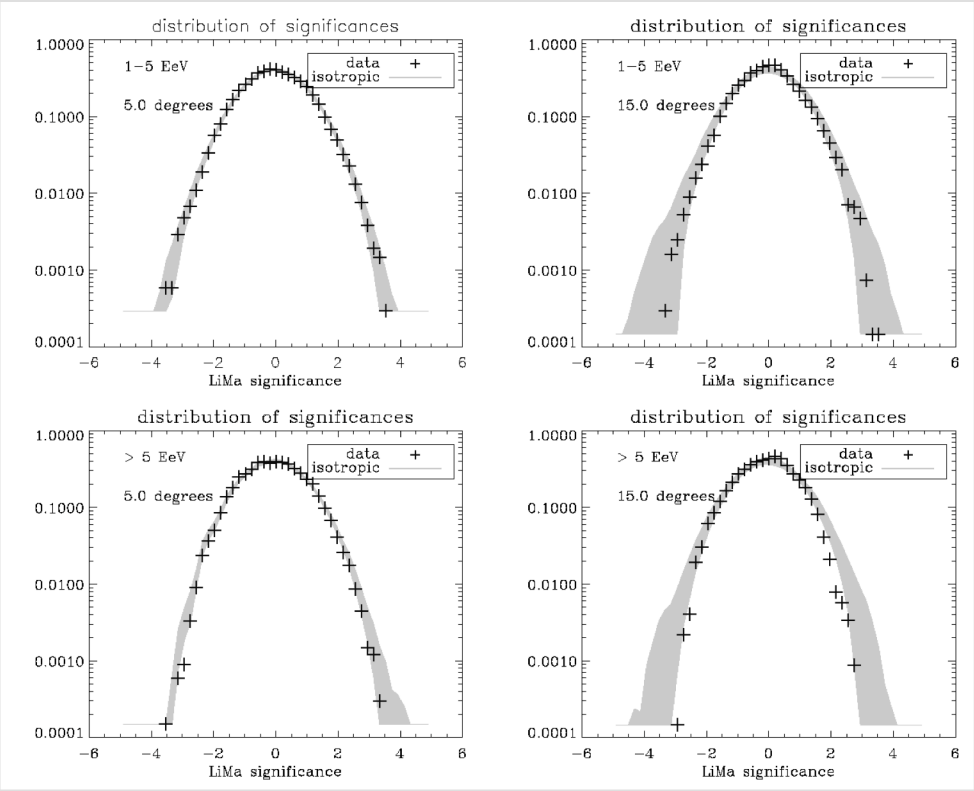
4% modulation 1 < E < 2 EeV

Search for locale excess in Auger data:

E = 1-5 EeV and E > 5 EeV x Angle = 5° and 15°



Look for excesses with top hats centered on each of 50K pixels



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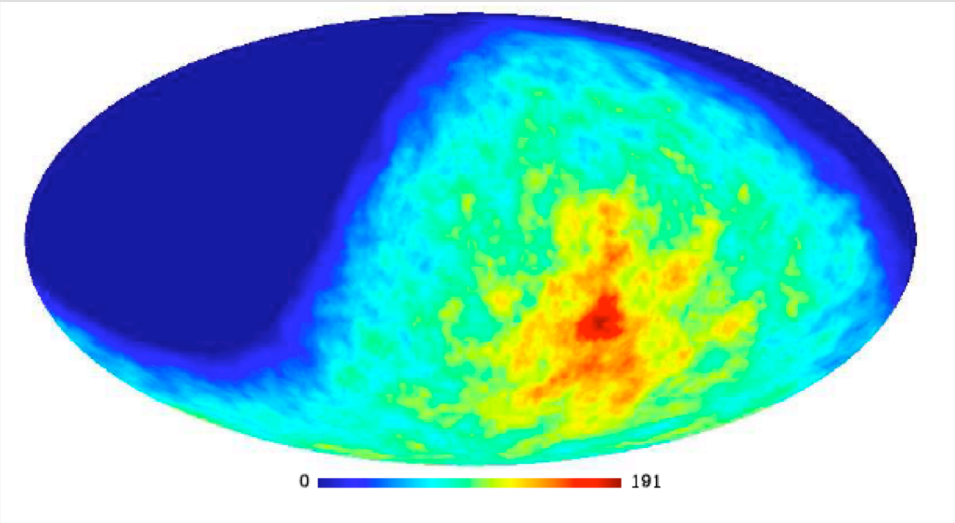

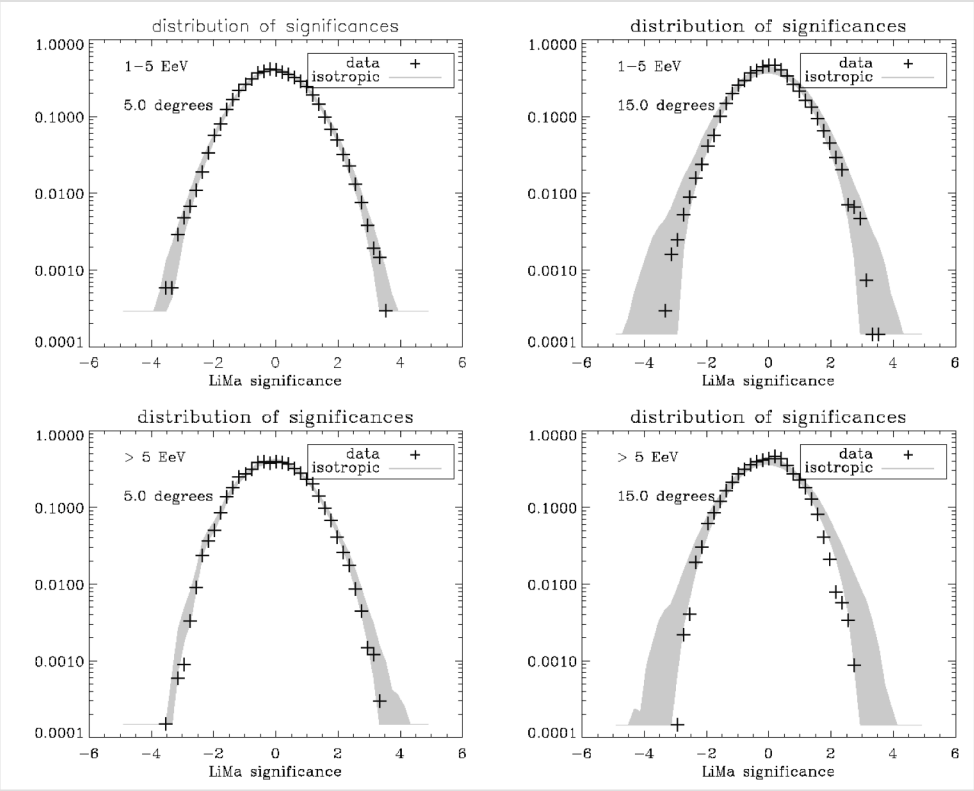

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No evidence for large scale anisotropy.