Auger-TA anisotropy working group report
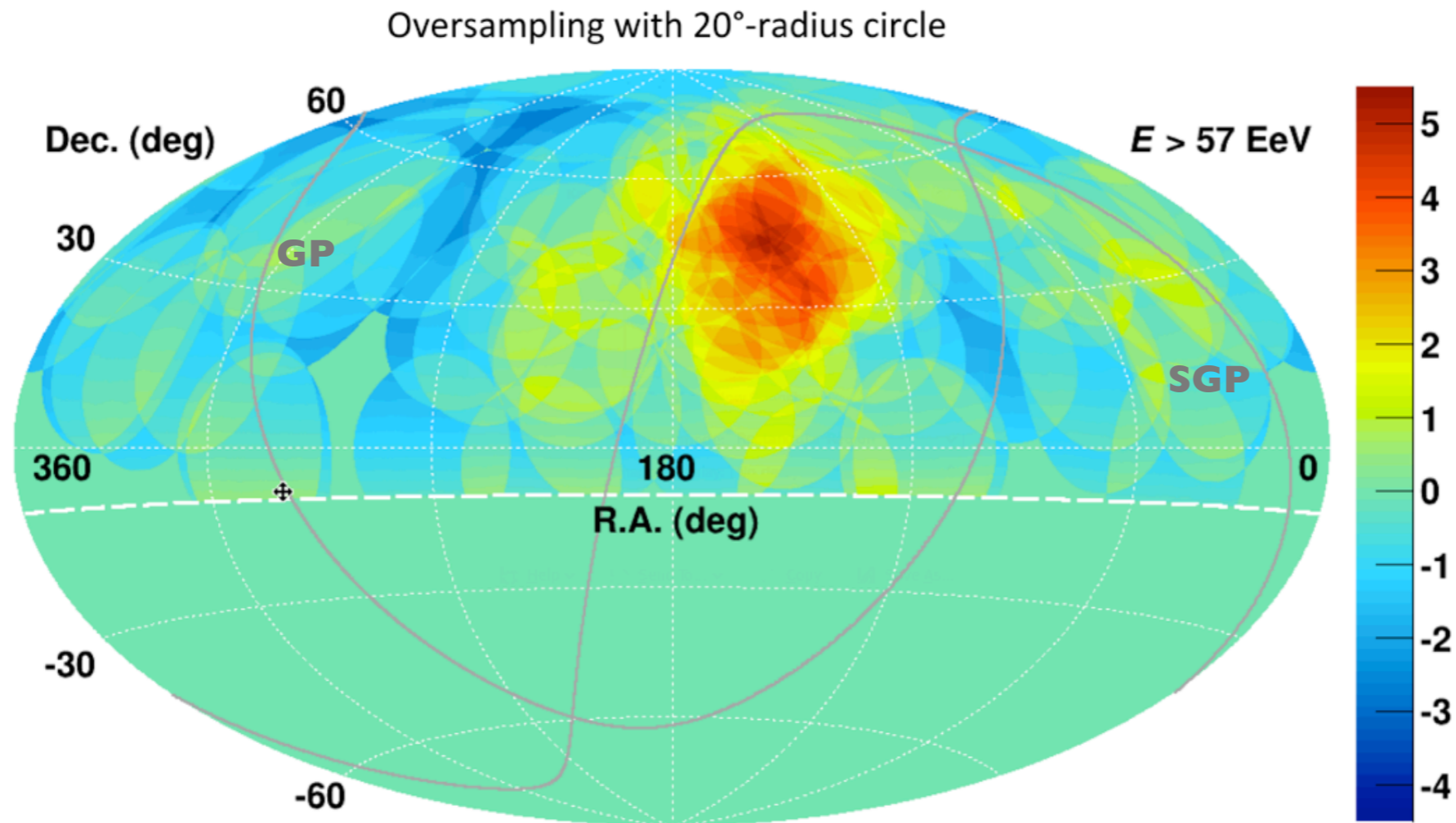
P. Tnyakov
H. Sagawa
I. Tkachev
D. Ivanov
G. Rubtsov

O. Deligny
D. Harari
E.M. Santos
M. Mostafa

TA hotspot

Significance Map (Li-Ma) 6 years

Oversampling with 20°-radius circle
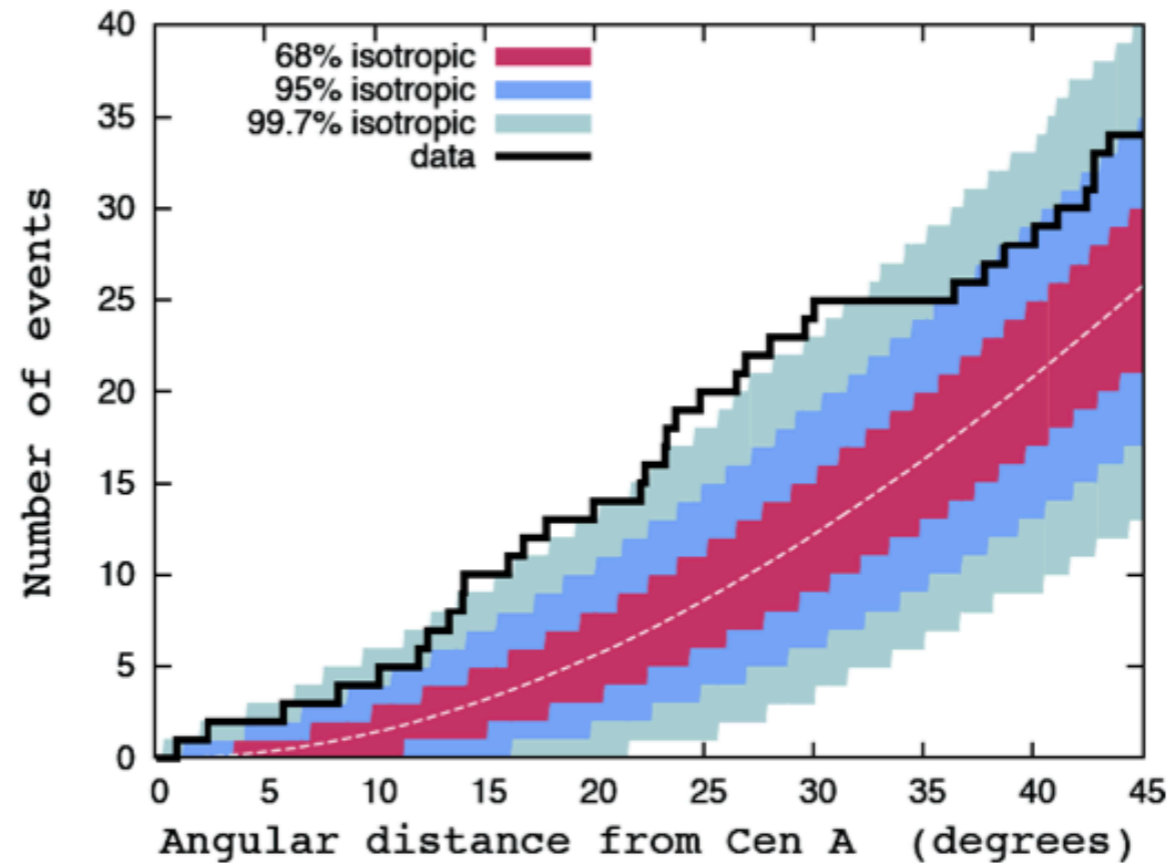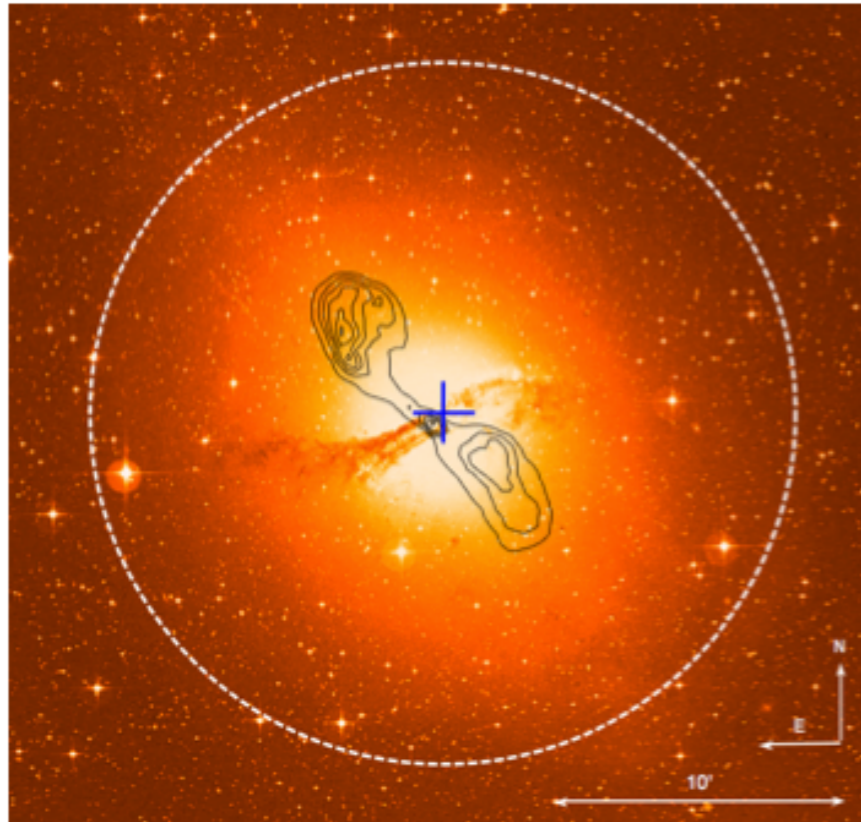

Max significance **5.55σ** (N$_{on}$ = 23, N$_{bg}$=5.49) for 6 years (5.07σ for 5 years)
Centered at R.A=148.4°, Dec.=44.5° (shifted from SGP by 17°)

➤ period: 2008.05.12 up to 2014.05.11 (6 years, + 1 yr as compared to arXiv:1404.5890)

➤ zenith angle up to 55 degrees

➤ loose cuts (edge cut removed, arXiv:1404.5890)

➤ 87 events above 57 EeV (=72+15)

post-trial (penalized) significance: 4σ

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Auger CenA excess

Cen A: optical image, radious contours
(VLA), VHE best fit position and 95%
C.L. (HESS)
(http://arxiv.org/pdf/0903.1582v1)

➤ Cumulative number of events with energy E > 55 EeV as
a function of angular distance from the direction of Cen A.

➤ Maximum deviation from isotropy at 24°
19 observed (7.6 expected) - Significance of 3.3 sigma

➤ KS test yields 4% isotropic probability

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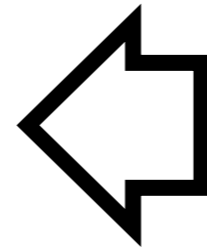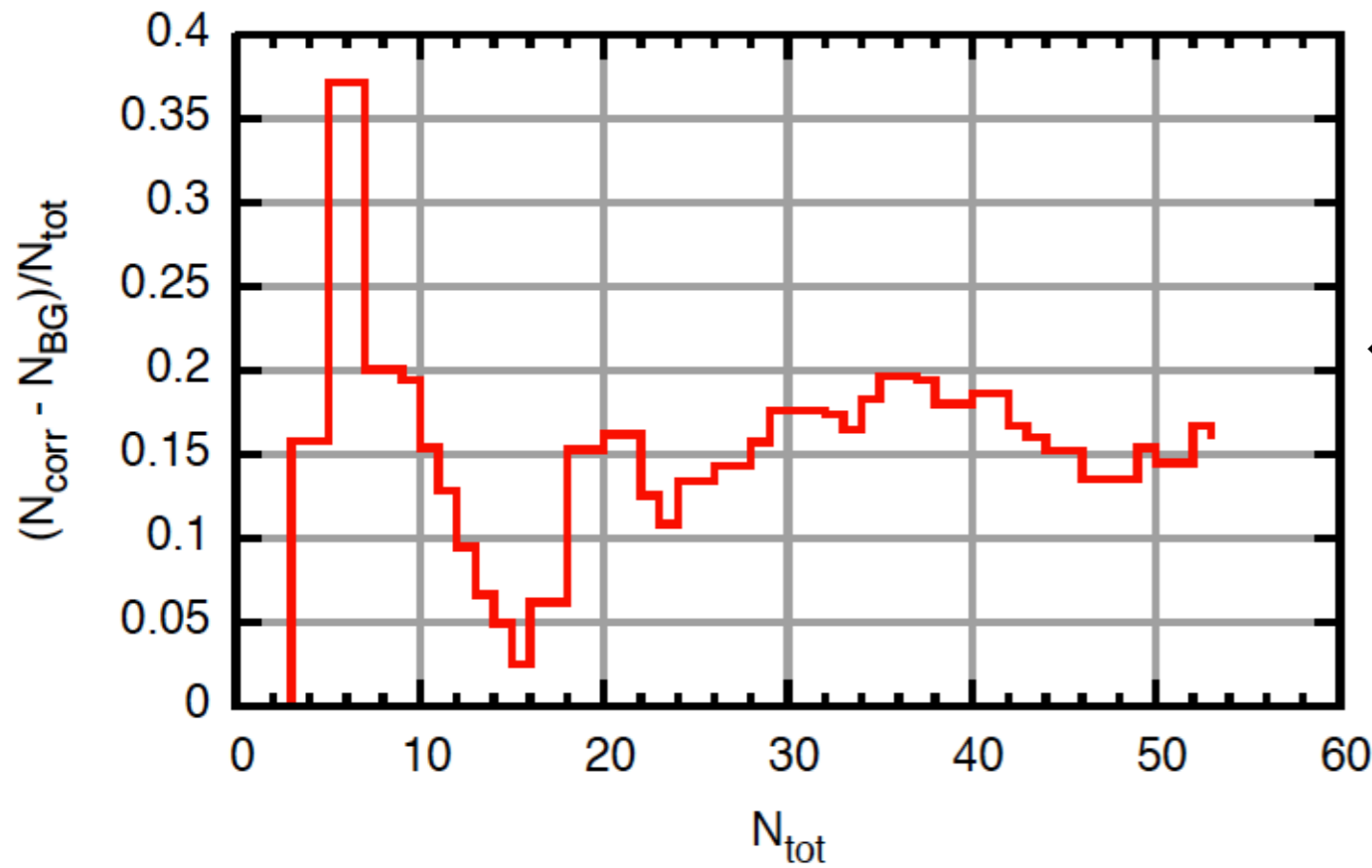# Correlation with AGN from VCV catalog

galactic coordinates
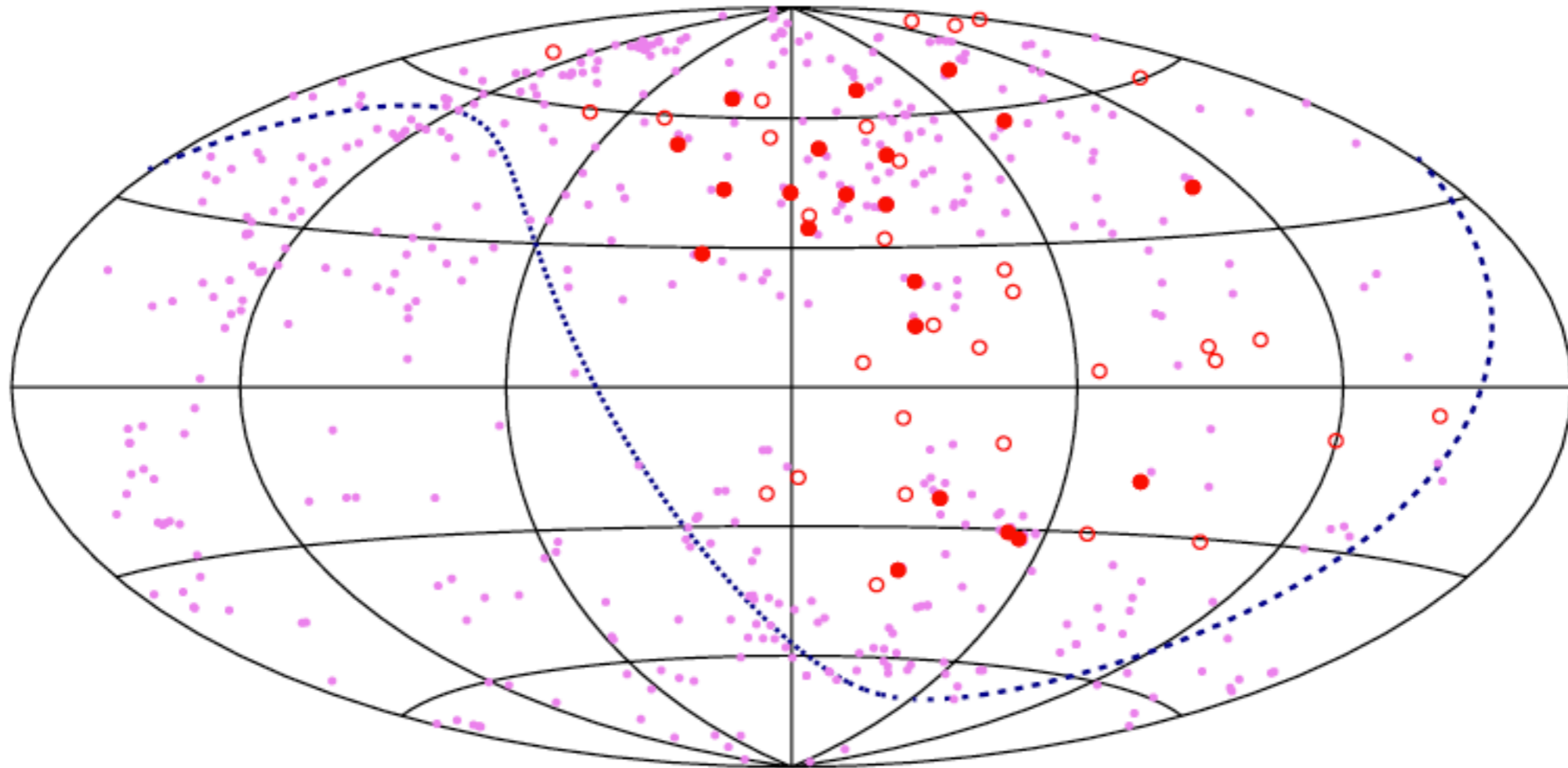
dots: VCV AGNs up to 75 Mpc
filled circles: TA events correlating within 3.1deg (E>57 EeV)
empty circles: non-correlating events
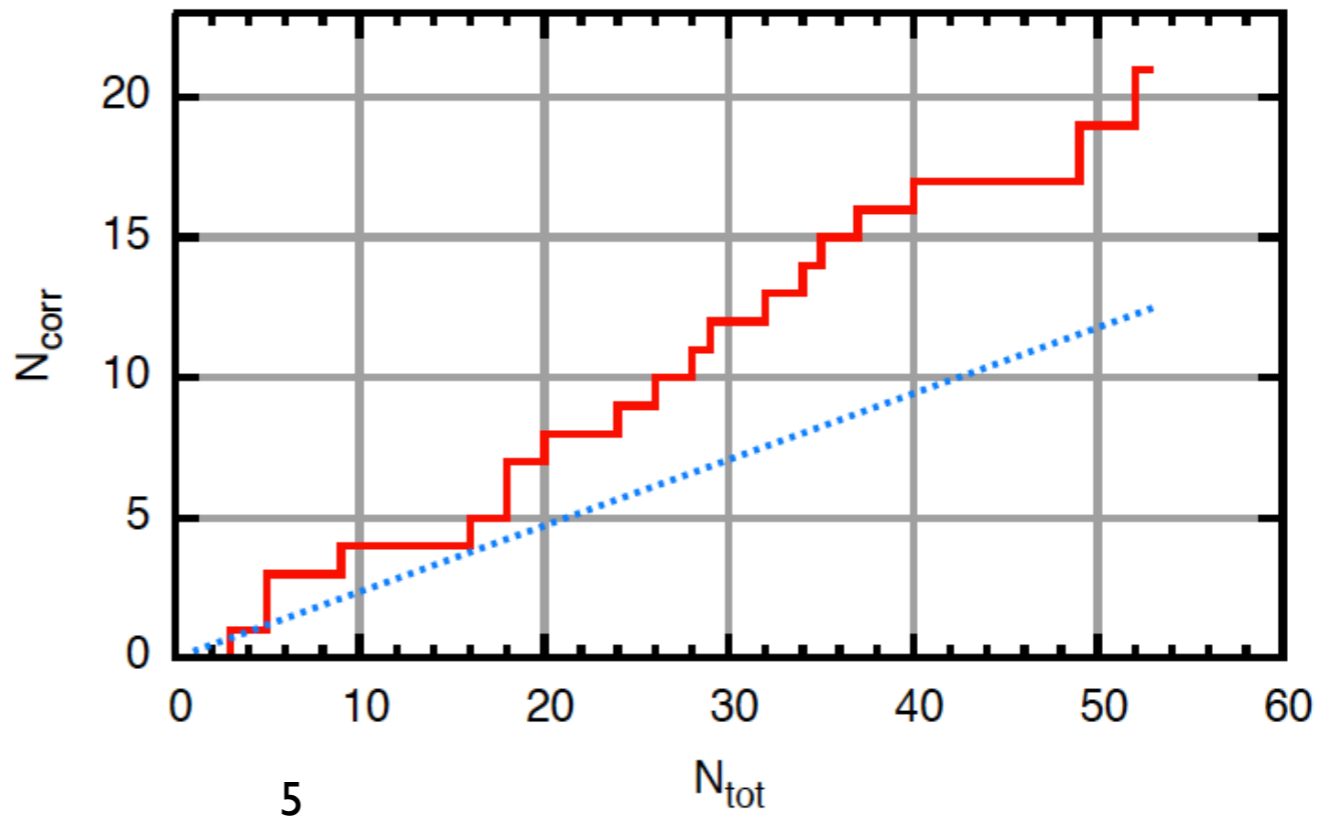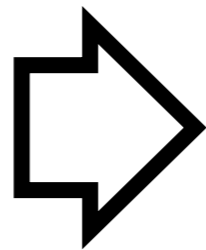
Correlation with AGN from VCV catalog

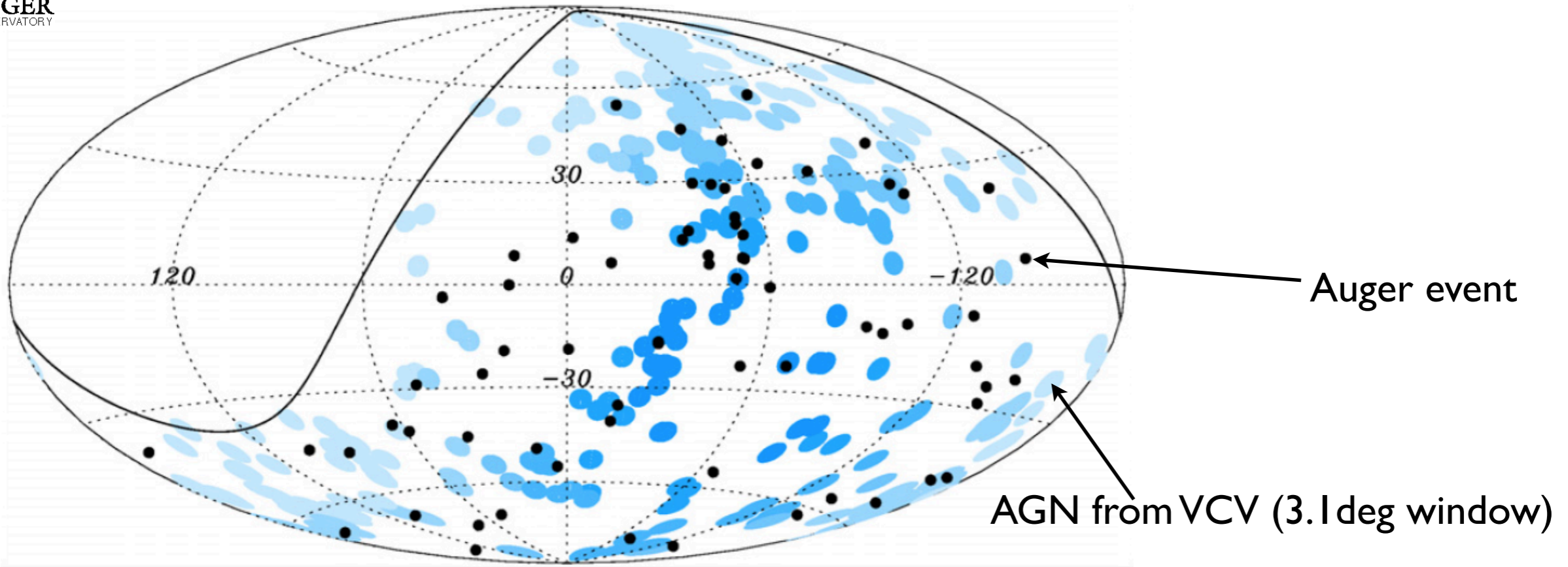Correlation excess

time ordered

correlations

background

N_{tot} = 53
N_{cor} = 21
N_{bkg} = 12.5
p-value = 7×10^{-3} (2.7σ)

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AGN correlation

Auger event

AGN from VCV (3.1deg window)
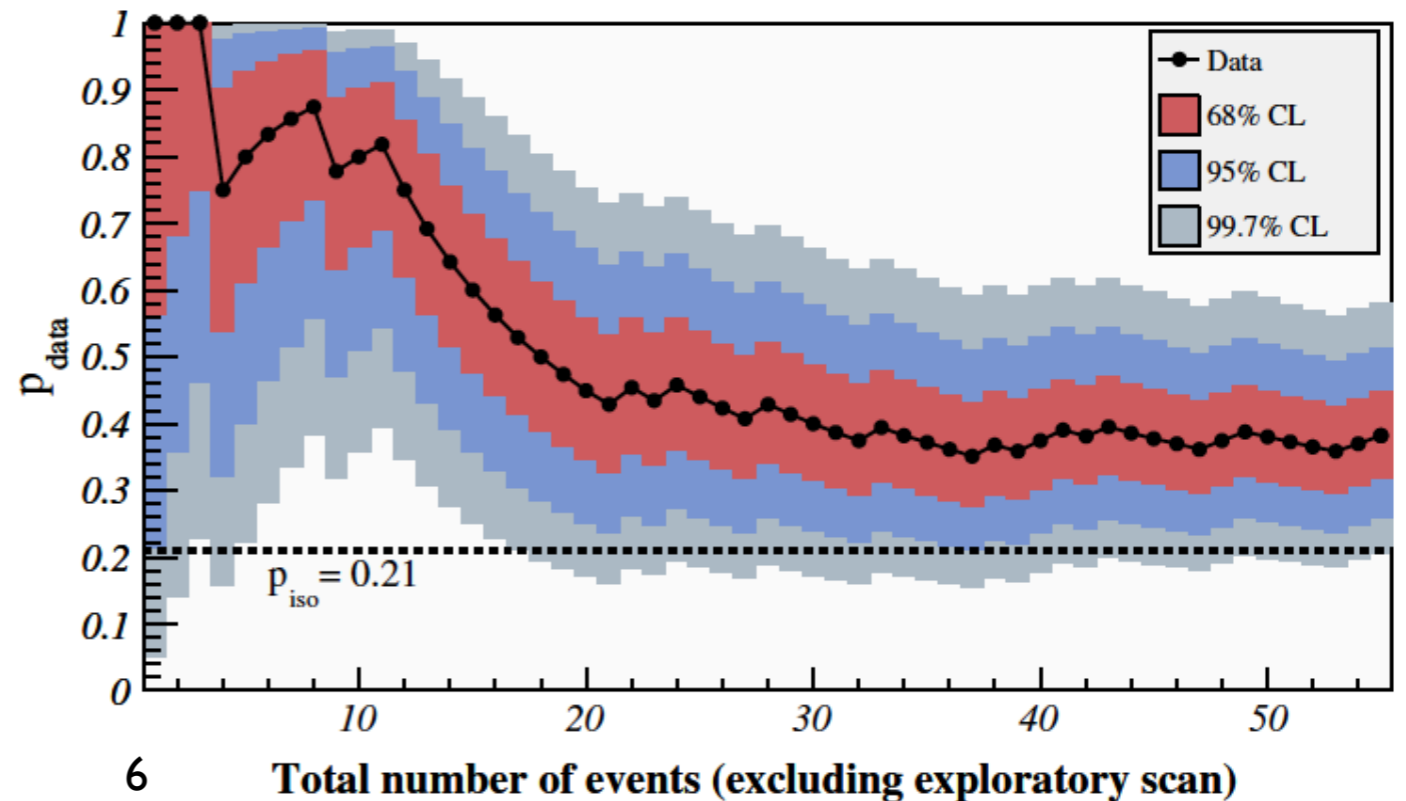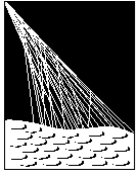
Angular window 3.1°
Energy threshold 55 EeV
Dmax: 75 Mpc (redshift < 0.018)

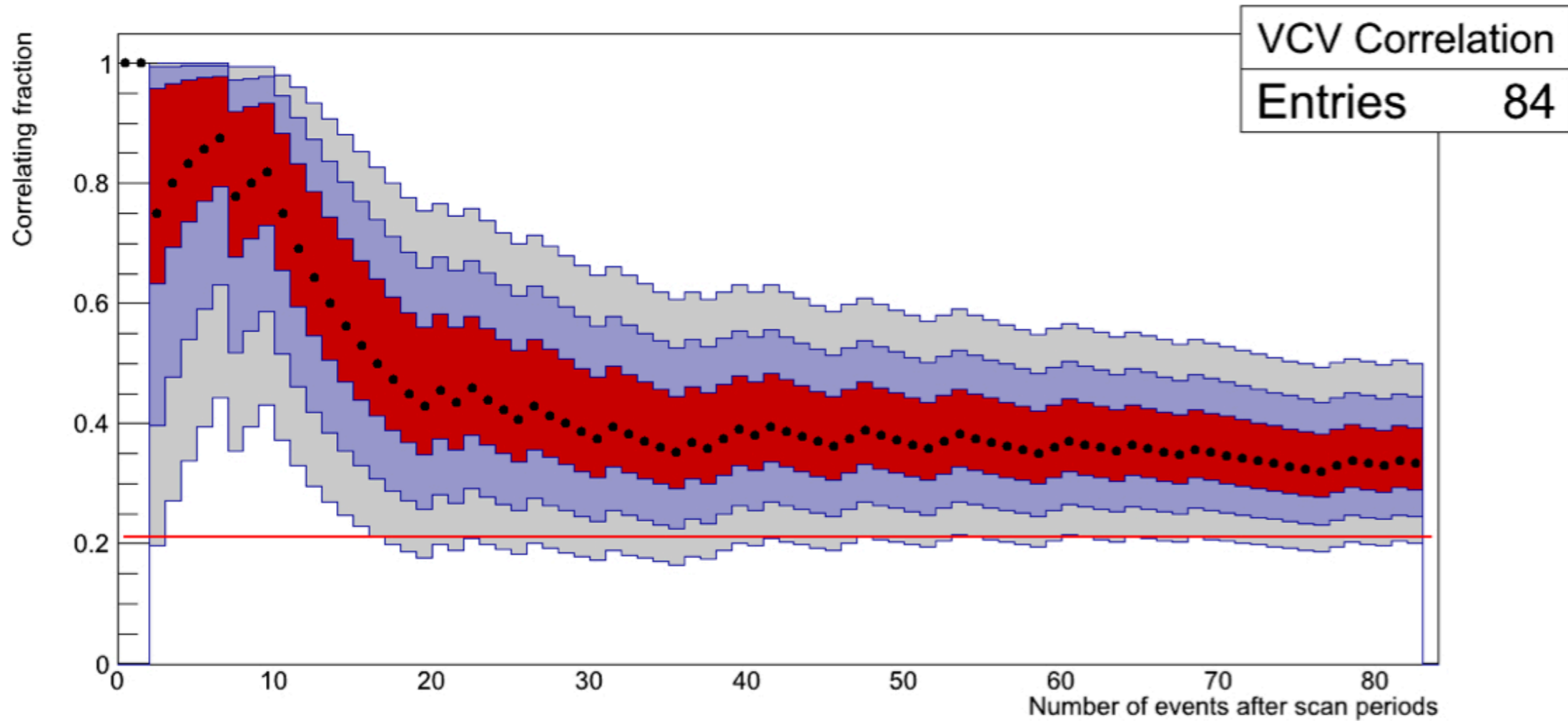**29/69 events (up to Dec 2009)**

21/55 (excluding exploratory scan)

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AGN correlation

28/84 events (up to Jun 2011)
(33 ± 5)%
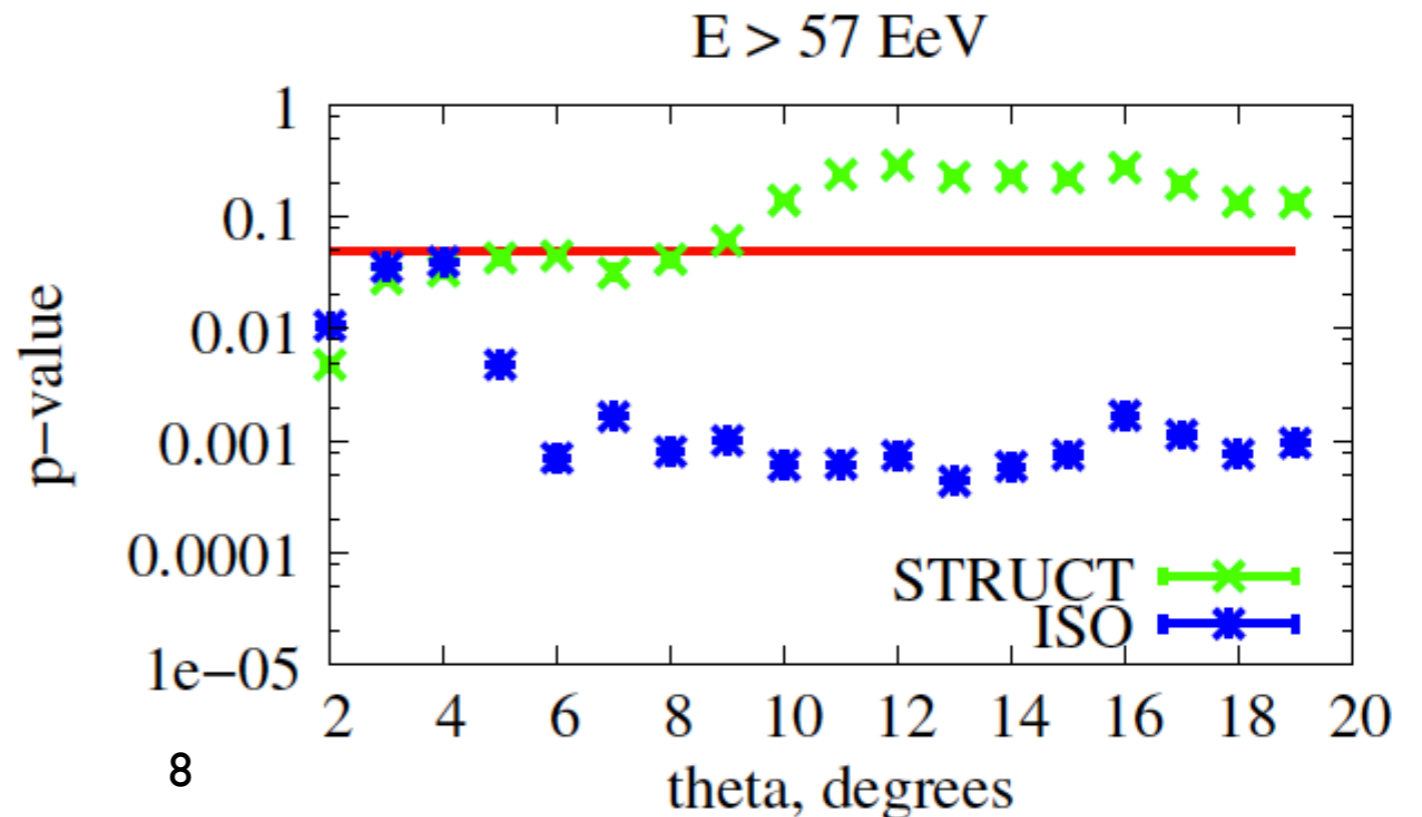**P=6x10⁻³**

Compatibility with LSS

smoothed @ 6 degrees
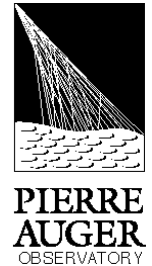
Flux expectation from LSS (2MASS)

TA event (>57 EeV)

Band normalization: each band integrates to 1/5 of the total flux

data compatible with LSS distribution

E > 57 EeV

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Correlation with LSS

$$F(\hat{\mathbf{n}}) = \frac{\varepsilon(\hat{\mathbf{n}})\mu(\hat{\mathbf{n}})}{I}\left[\frac{f_{iso}}{\Omega} + (1 - f_{iso})\frac{\phi(\hat{\mathbf{n}})}{\langle\phi\rangle}\right]$$
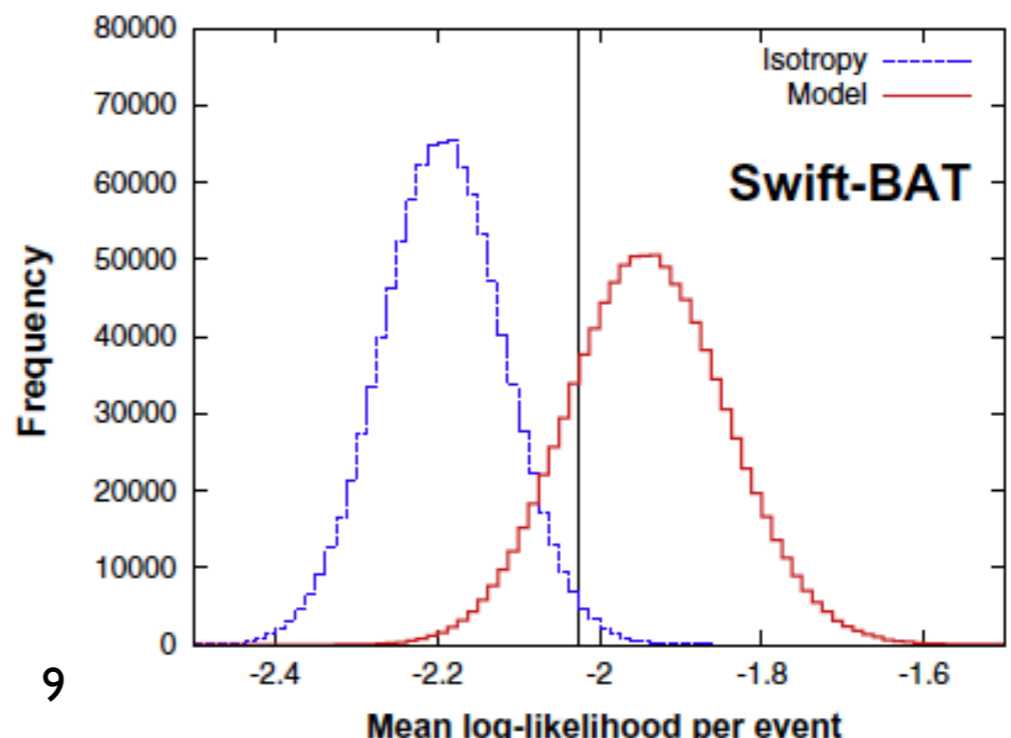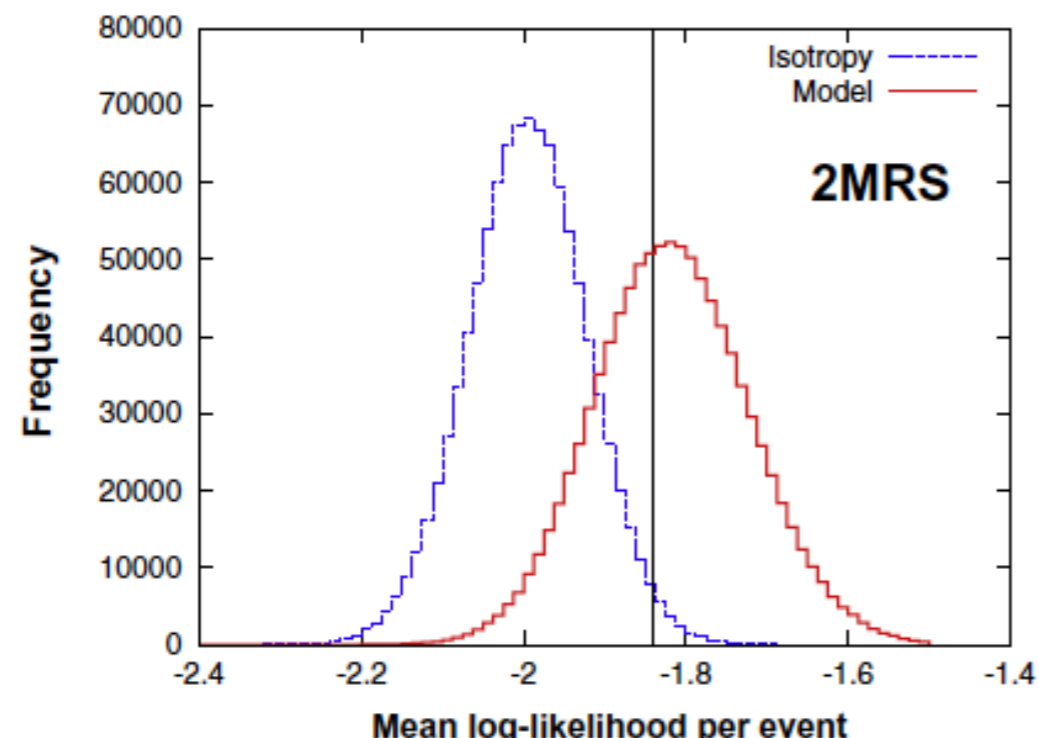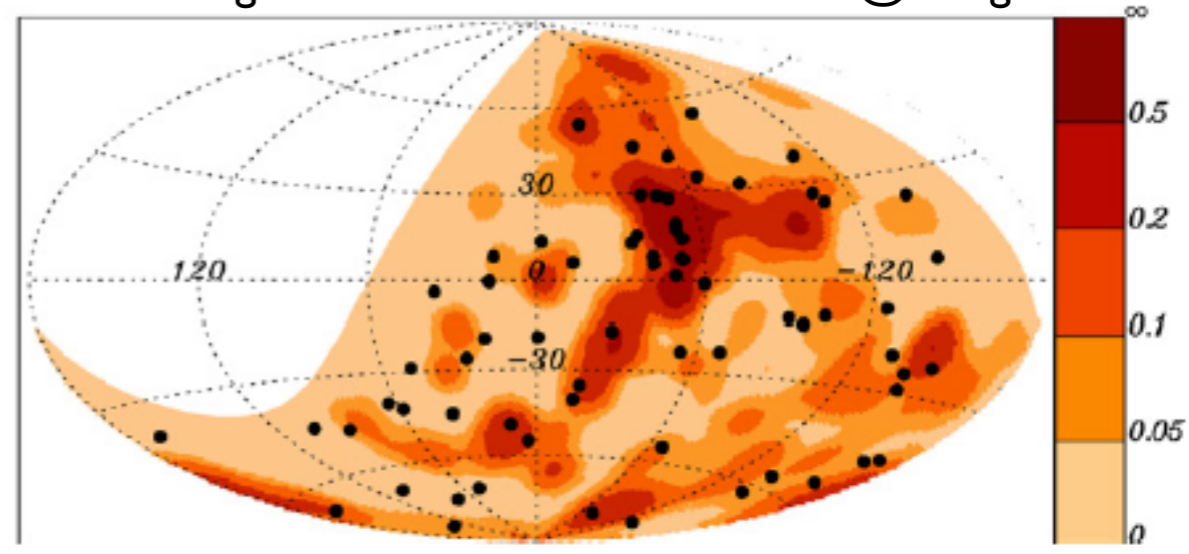
$$\phi(\hat{\mathbf{n}}) = \sum_{i=1}^{N_{cat}} w(z_i)e^{-\frac{d(\hat{\mathbf{n}}_i,\hat{\mathbf{n}})^2}{2\sigma^2}}$$

data used to get best-fit values of f_{iso} and σ

AR and magnetic deflections

source flux (IR or X-ray) and GZK cutoff included

flux weighted 2MRS and smoothed @ 5deg:

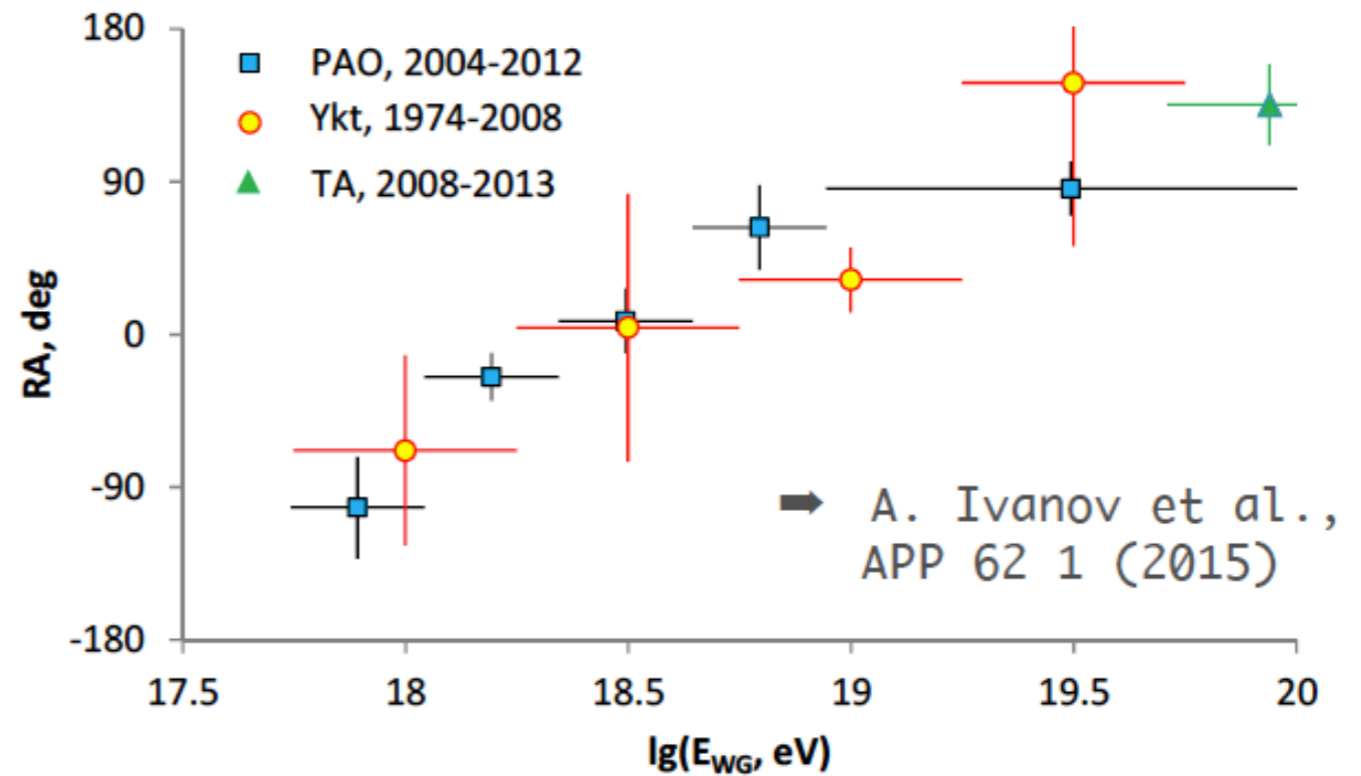flux weighted Swift-BAT and smoothed @ 5deg:

2MRS

Swift-BAT
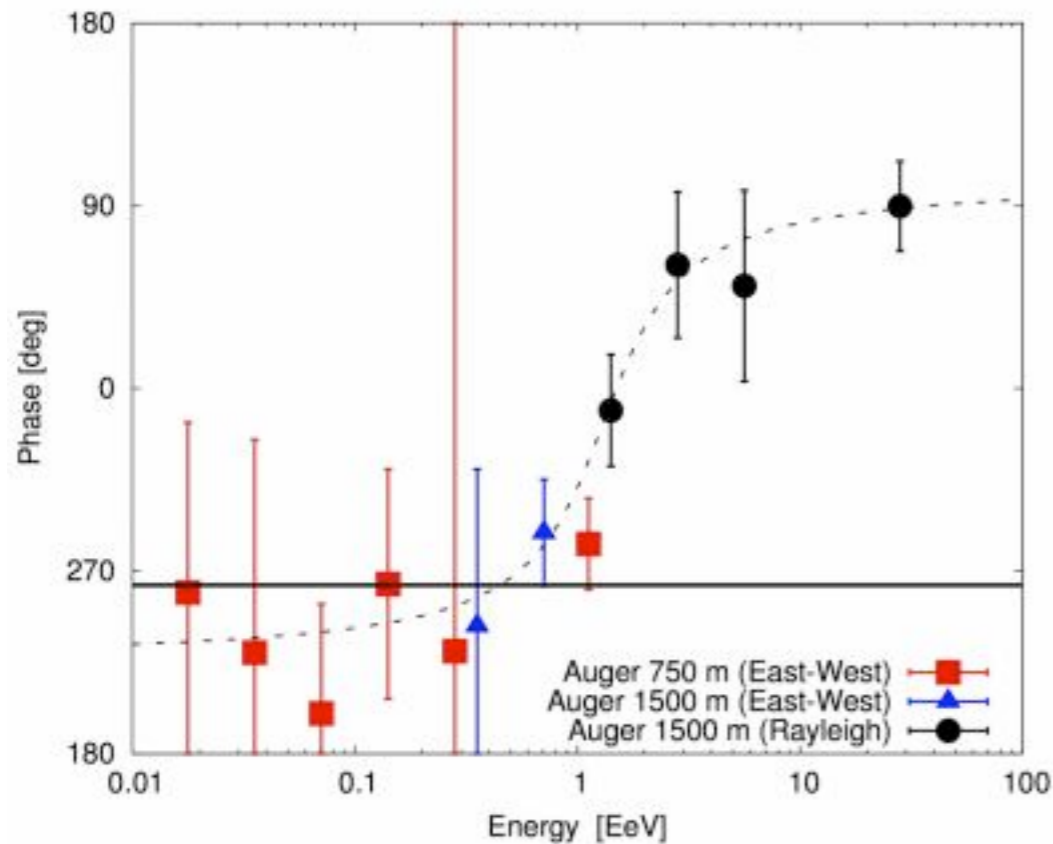
$$\mathcal{LL} = \sum_{k=1}^{N_{data}} \ln F(\hat{\mathbf{n}}_k)$$

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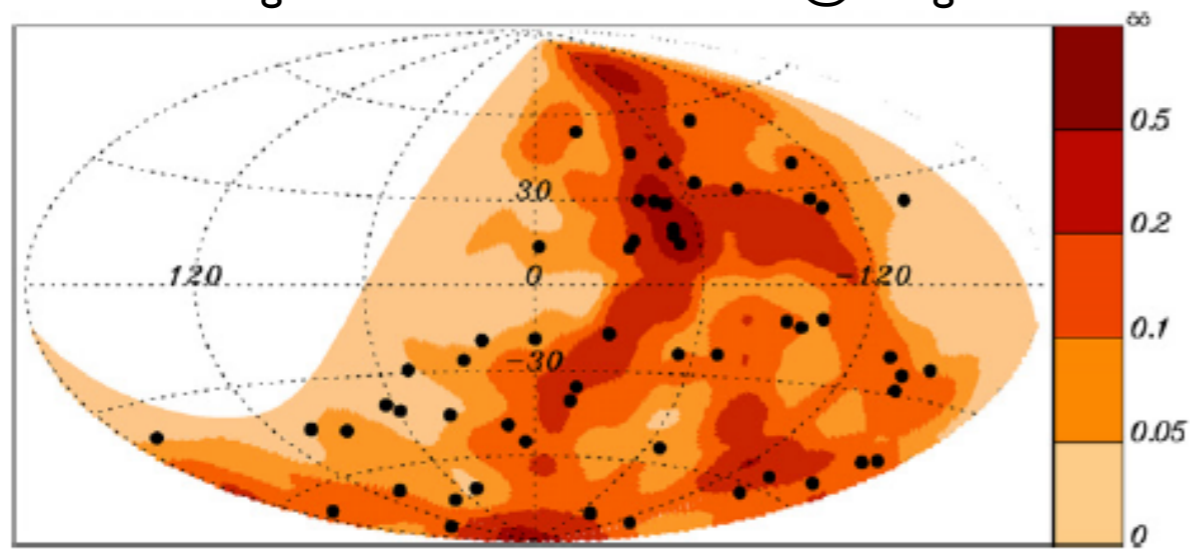
Harmonic Analysis in RA - phase

Fourier expansion of RA distribution: $\Phi(\alpha) = a_0 + \sum_{n>0} a_n^c \cos n\alpha + \sum_{n>0} a_n^s \sin n\alpha.$

$$\varphi = \operatorname{atan}(a_1^s/a_1^c)$$

➡ A. Ivanov et al., APP 62 1 (2015)

Non-random phases over a wide energy ranges
Prescription setup in Auger

Full sky coverage for E>10 EeV

➤ Anisotropy studies with combined Auger-TA data
➤ Enhanced statistics
➤ Full sky coverage
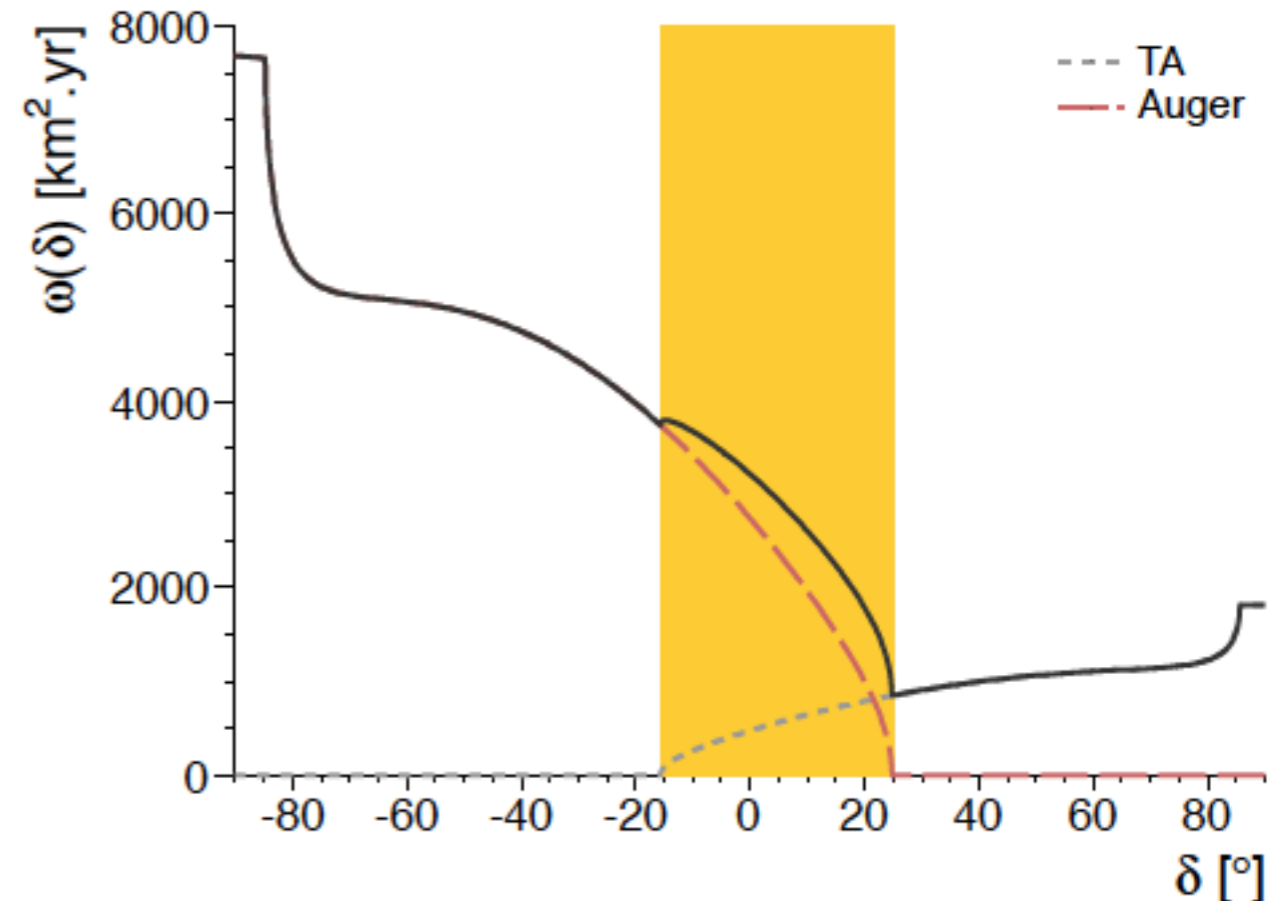➤ No need to bound multipole expansion

TA   : [0-55 deg] ; E > 10 EeV

Auger: [0-60 deg] ; E > 8.5 EeV

Energy thresholds lead to simple geometrical exposure in local coordinates:

$$\propto \sin\theta \cos\theta$$

Unavoidable uncertainty in the relative exposures:

$$\omega(\mathbf{n}; b) = \omega_{\mathrm{TA}}(\mathbf{n}) + b\,\omega_{\mathrm{Auger}}(\mathbf{n})$$

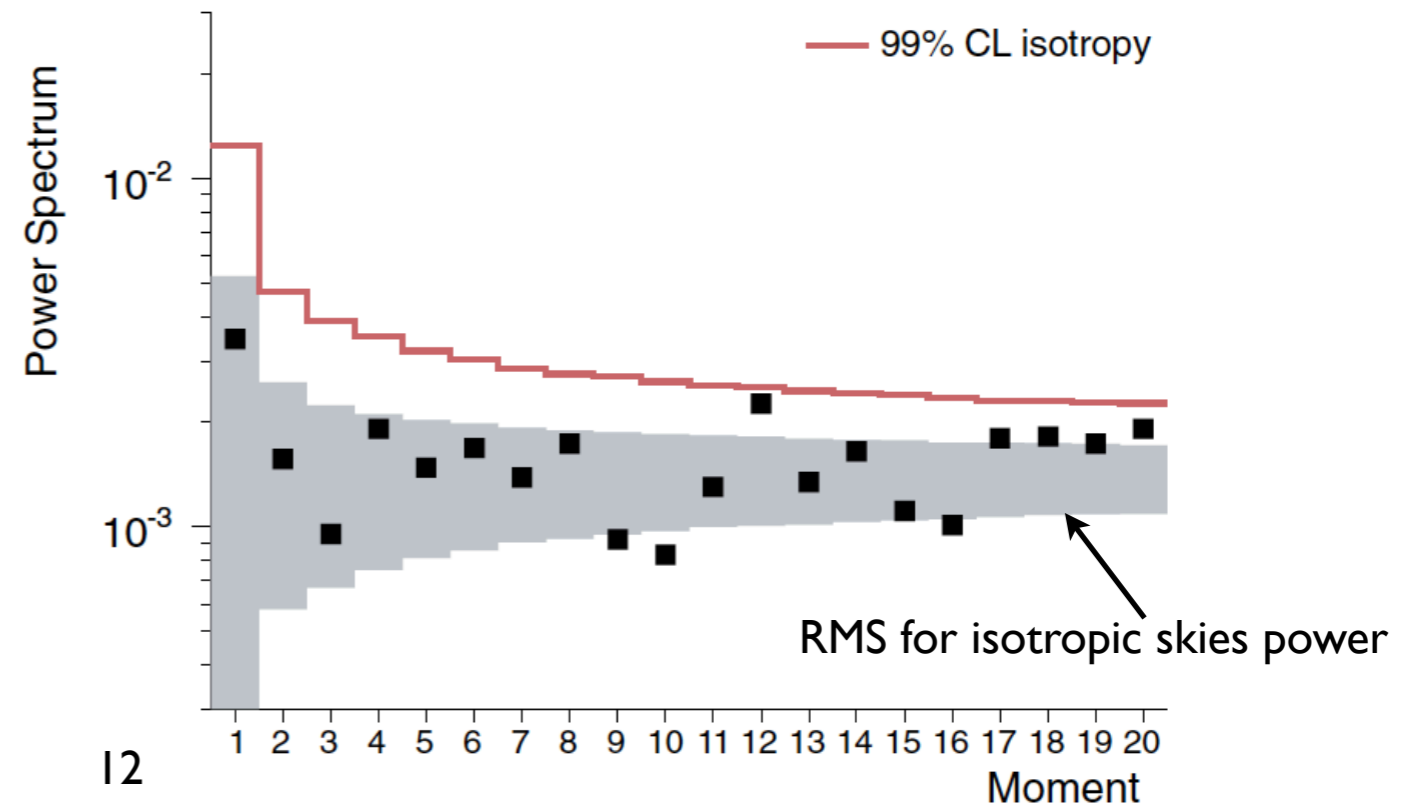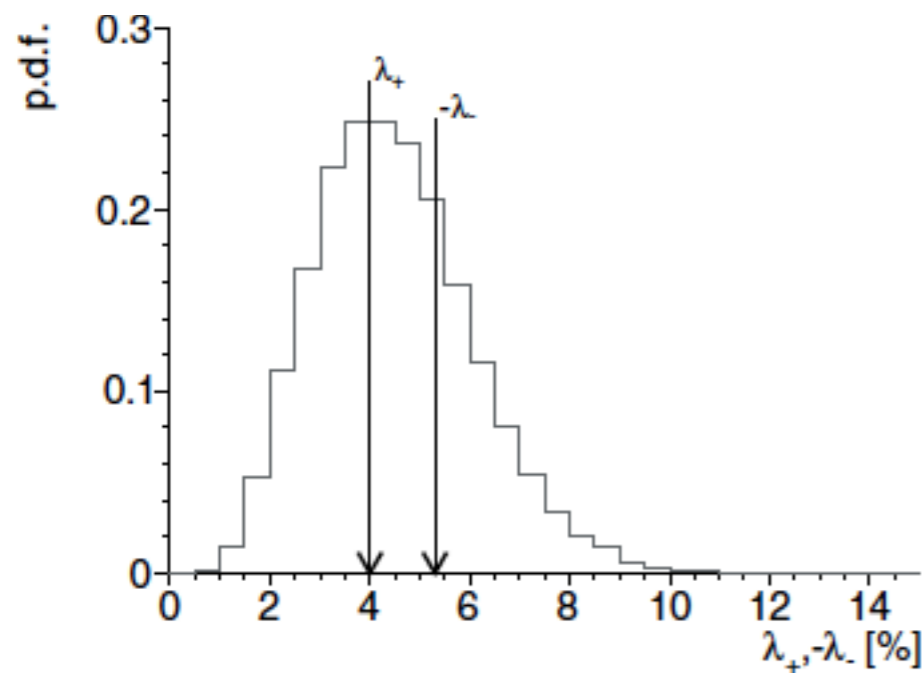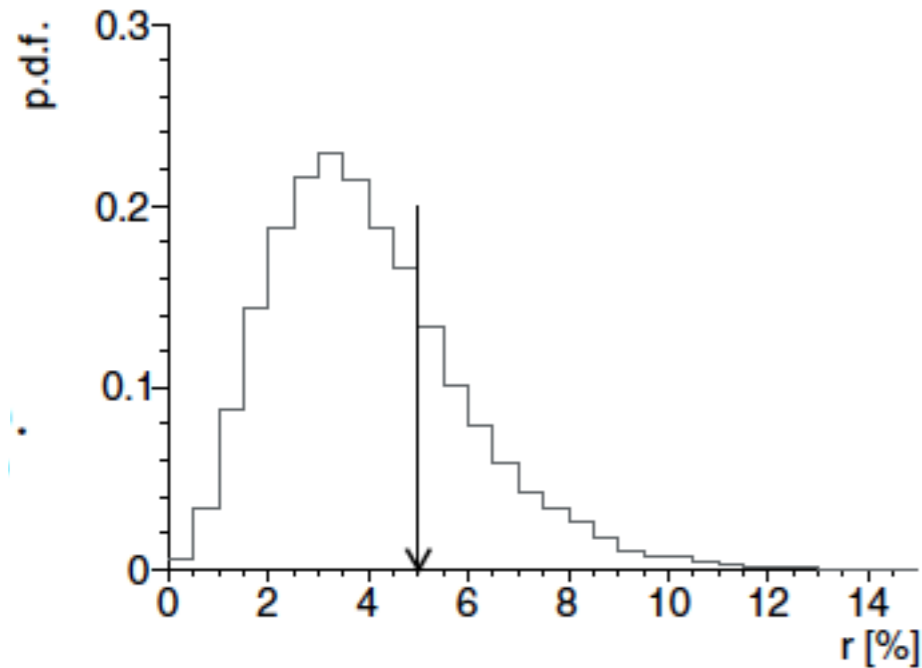➤ b: factor absorbing systematics of any origin (for example, energy scale)
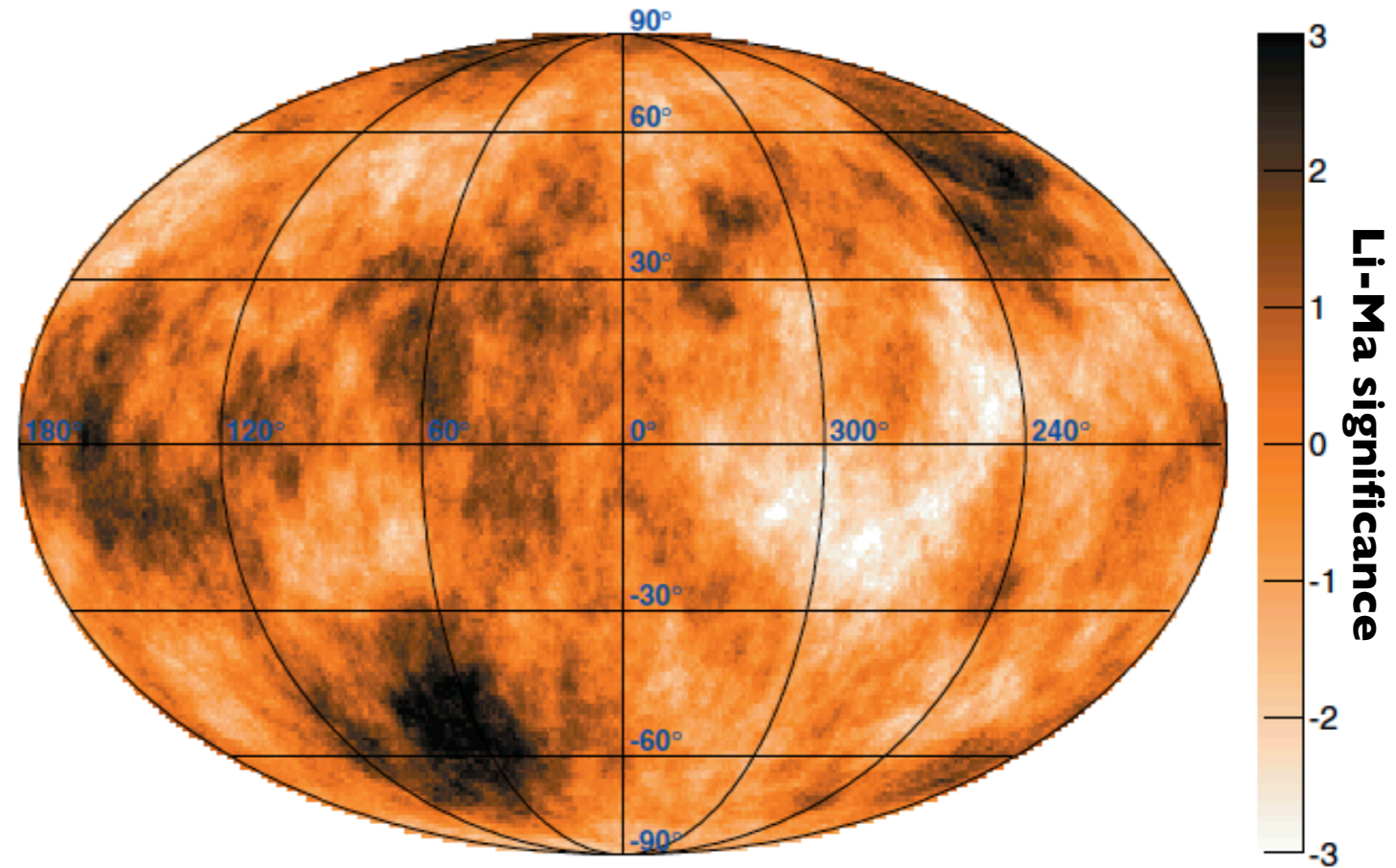
➤ derived by forcing both experiments to see the same flux in the overlap region

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Full sky coverage for E>10 EeV

	Auger	TA
Exposure [km2 sr yr]	31440	6040
# events (overlap)	~3400	~650
# events (total)	~10900	~1800

Equatorial Coordinates - 15° smoothing

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Summary

- Hotspot observed for TA events above 57 EeV. Post-trial probability of 4.0 (3.4) sigmas for 6 years (5 years). (RA, dec) = (148.4, 44.5) degrees

- Highest energy TA events show compatibility with LSS (2MASS as template)

- No statistically significant correlation with AGNs from VCV observed

- Auger events (>57 EeV) around CenA show maximum deviation from isotropy around 24 degrees

- HE events show compatibility with LSS tracers such as IR galaxies (2MRS) or AGNs detected in X-rays (Swift-BAT).

- Correlation with AGNs with events up to June 2011 at the level of 33%, compared to 21% from an isotropic sky

- Non-random phases over a broad energy range

- Combined sky maps above 10 EeV provide full sky coverage with great potential for large scale anisotropy studies