Cosmic Ray data at the highest energies
Beyond a EeV

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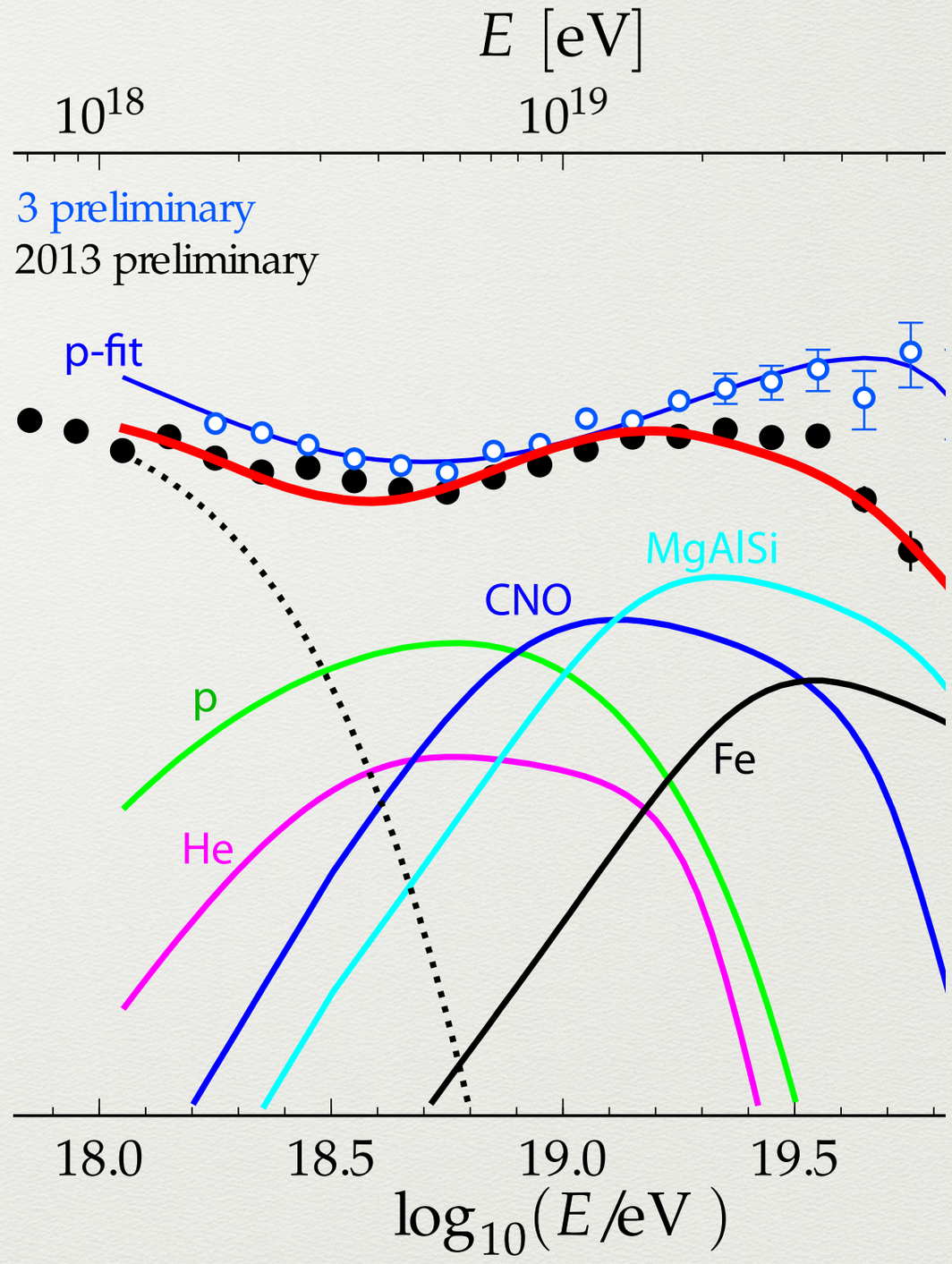
LPNHE PARIS

Data from Auger and Telescope Array

- Spectrum
- Anisotropies
- Mass composition

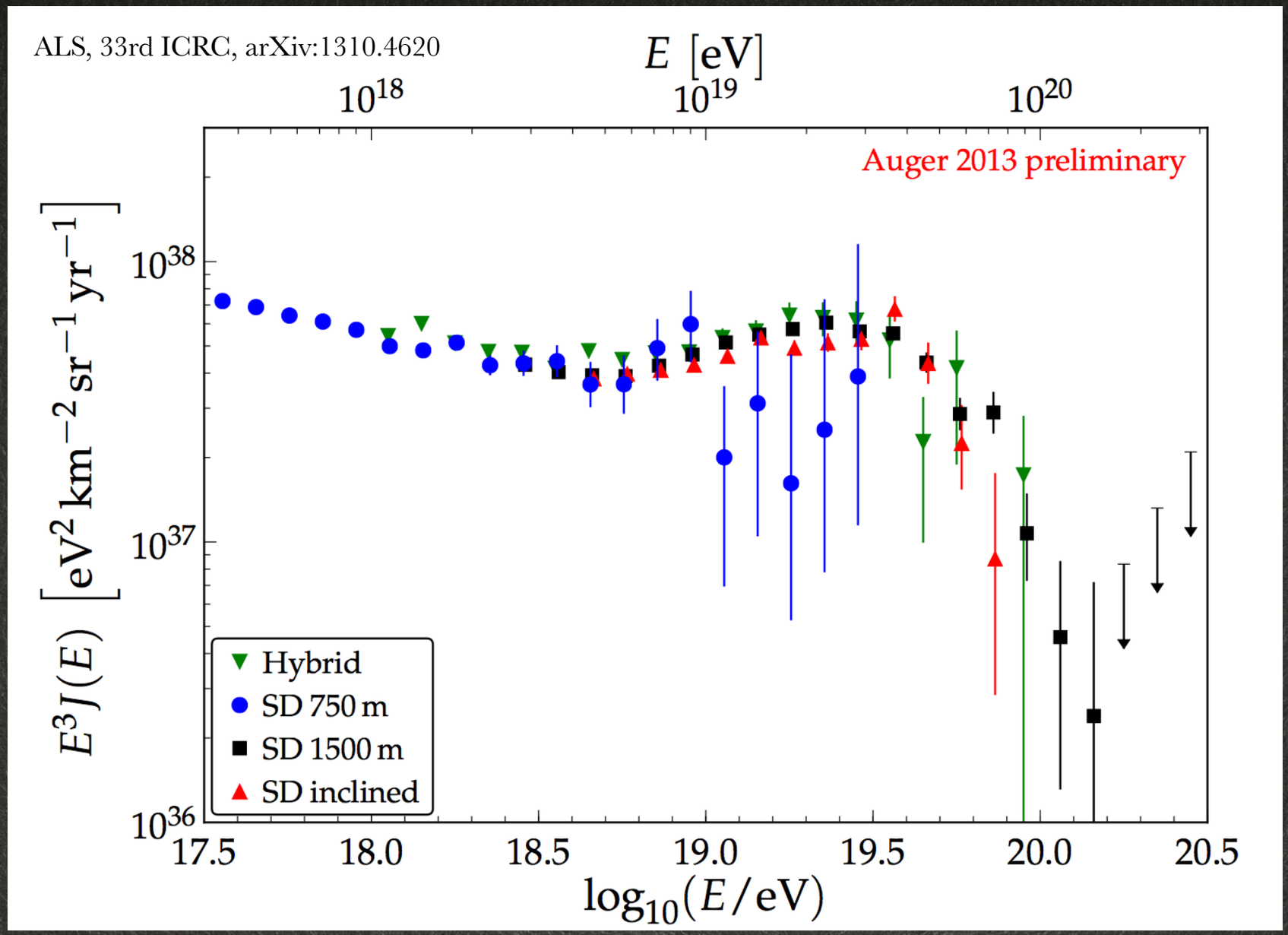
Spectrum

- Auger
- TA
- Combined

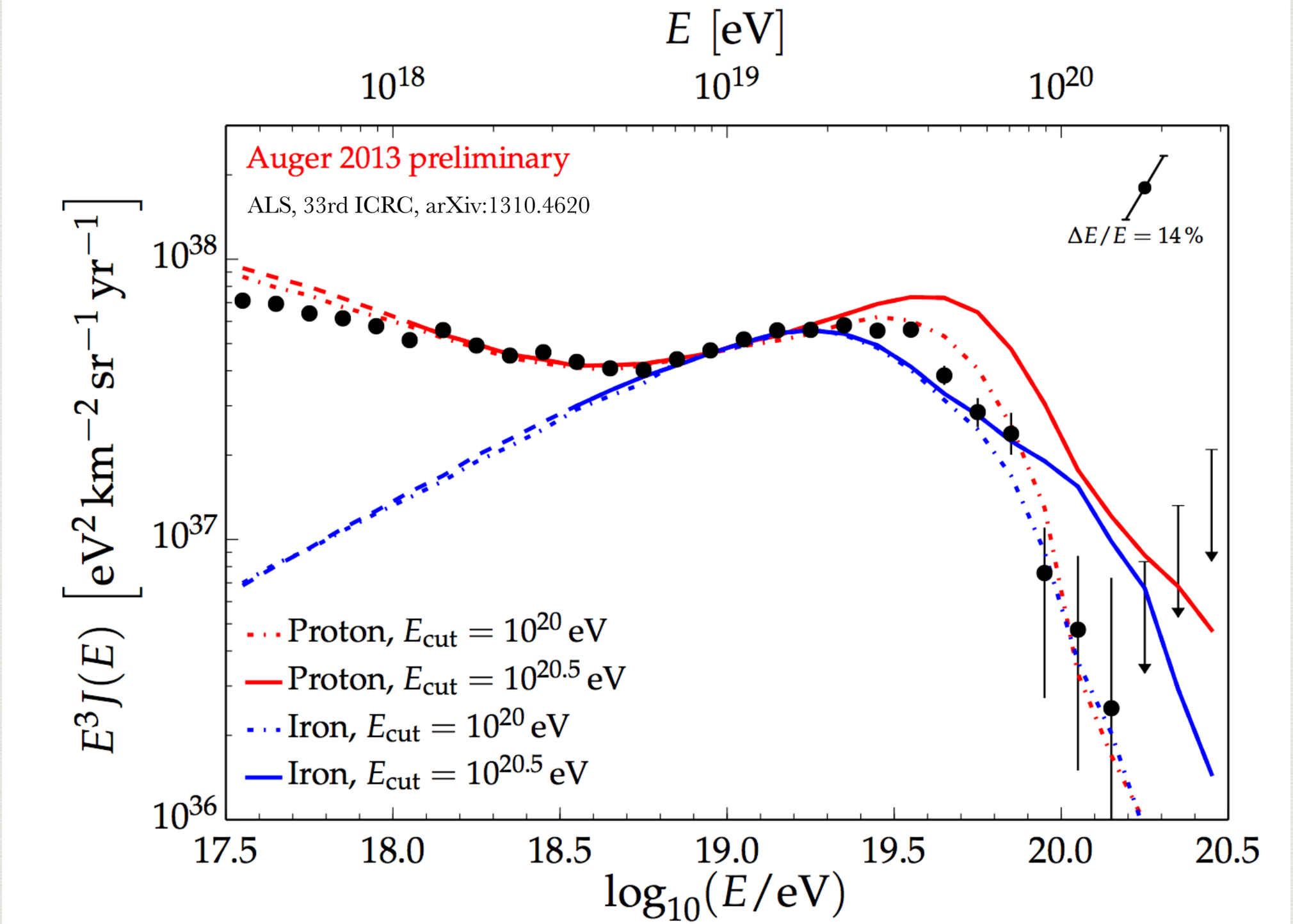


Auger

ALS, 33rd ICRC, arXiv:1310.4620



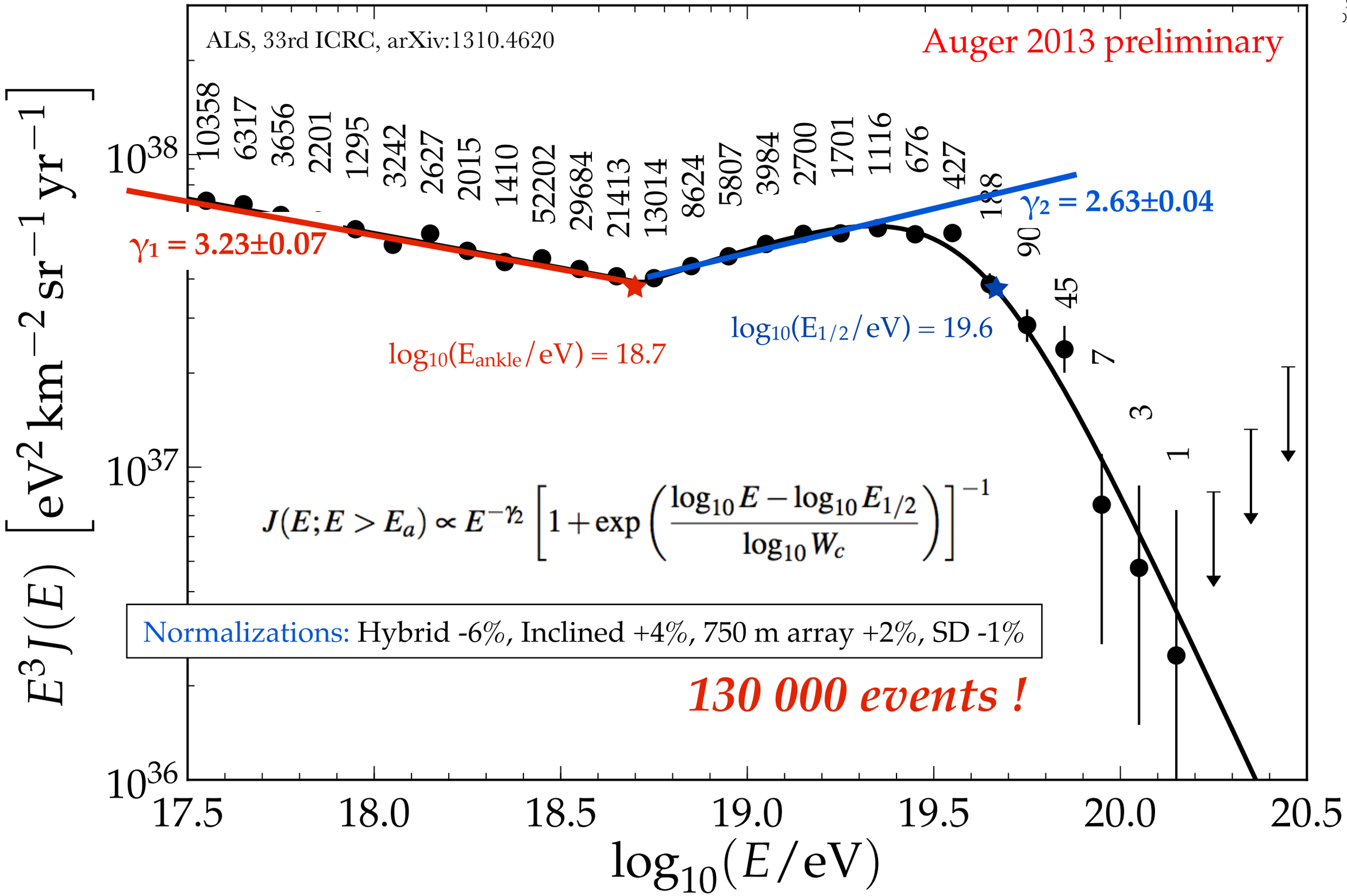
	Auger SD			Auger hybrid
	1500 m vertical	**1500 m inclined**	**750 m vertical**	
Data taking period	01/2004 - 12/2012	01/2004 - 12/2012	08/2008 - 12/2012	11/2005 - 12/2012
Exposure $[\mathrm{km}^2\,\mathrm{sr\,yr}]$	31645 ± 950	8027 ± 240	79 ± 4	-
Zenith angles [°]	$0-60$	$62-80$	$0-55$	$0-60$
Threshold energy E_{eff} [eV]	3×10^{18}	4×10^{18}	3×10^{17}	10^{18}
No. of events ($E > E_{\mathrm{eff}}$)	82318	11074	29585	11155
No. of events (golden hybrids)	1475	175	414	-
Energy calibration (A) [EeV]	0.190 ± 0.005	5.61 ± 0.1	$(1.21 \pm 0.07) \cdot 10^{-2}$	-
Energy calibration (B)	1.025 ± 0.007	0.985 ± 0.02	1.03 ± 0.02	-



Auger spectrum together with some prediction from different sources hypotheses
p = 2.3 E^ (-p); m = -3 (Fe) 2 (p) (1+z) ^ (m+3)

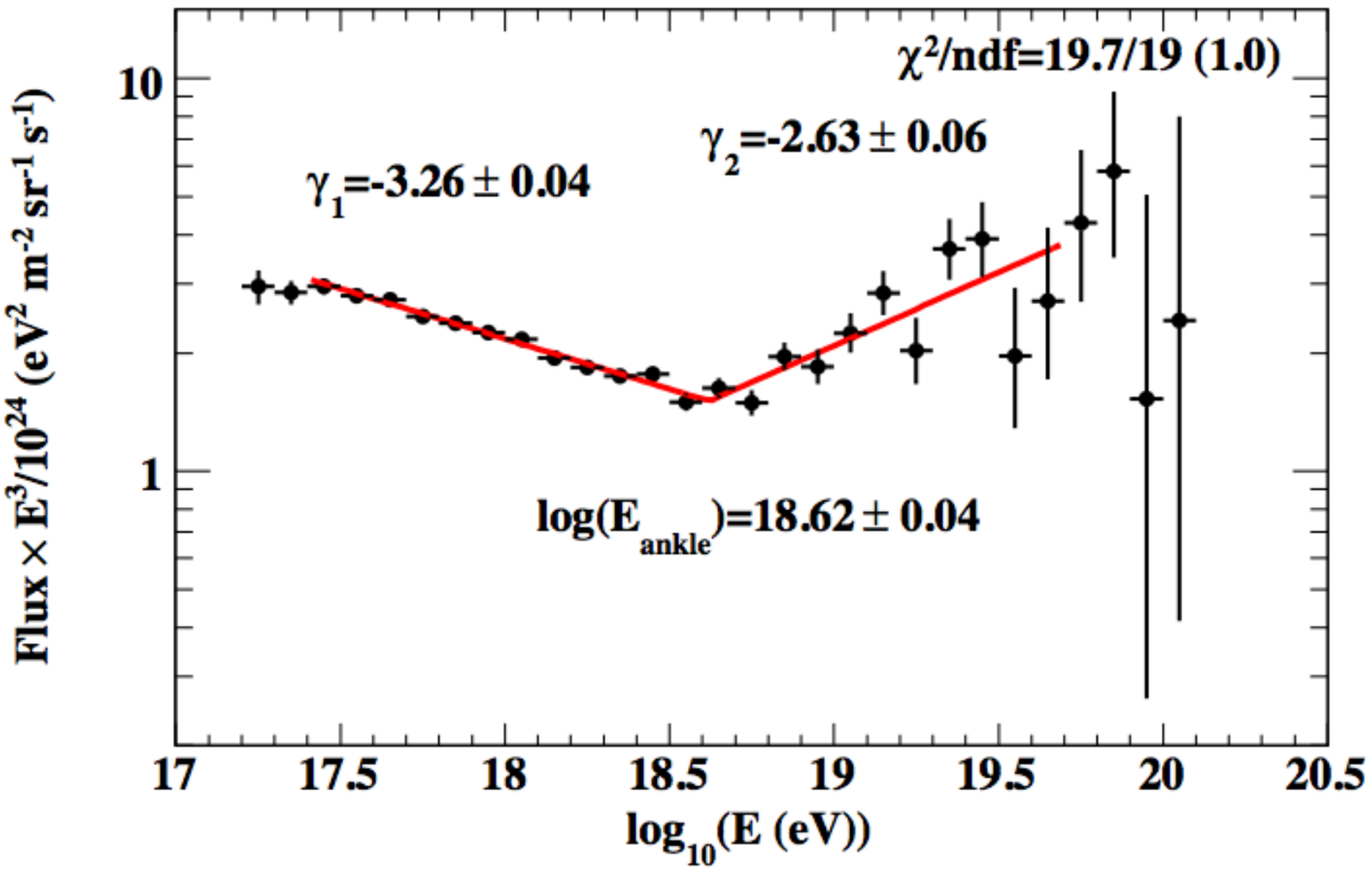
THE AUGER ENERGY SPECTRUM

PIERRE AUGER OBSERVATORY



TA

TA coll., Astropart. phys. arXiv:1511.07510



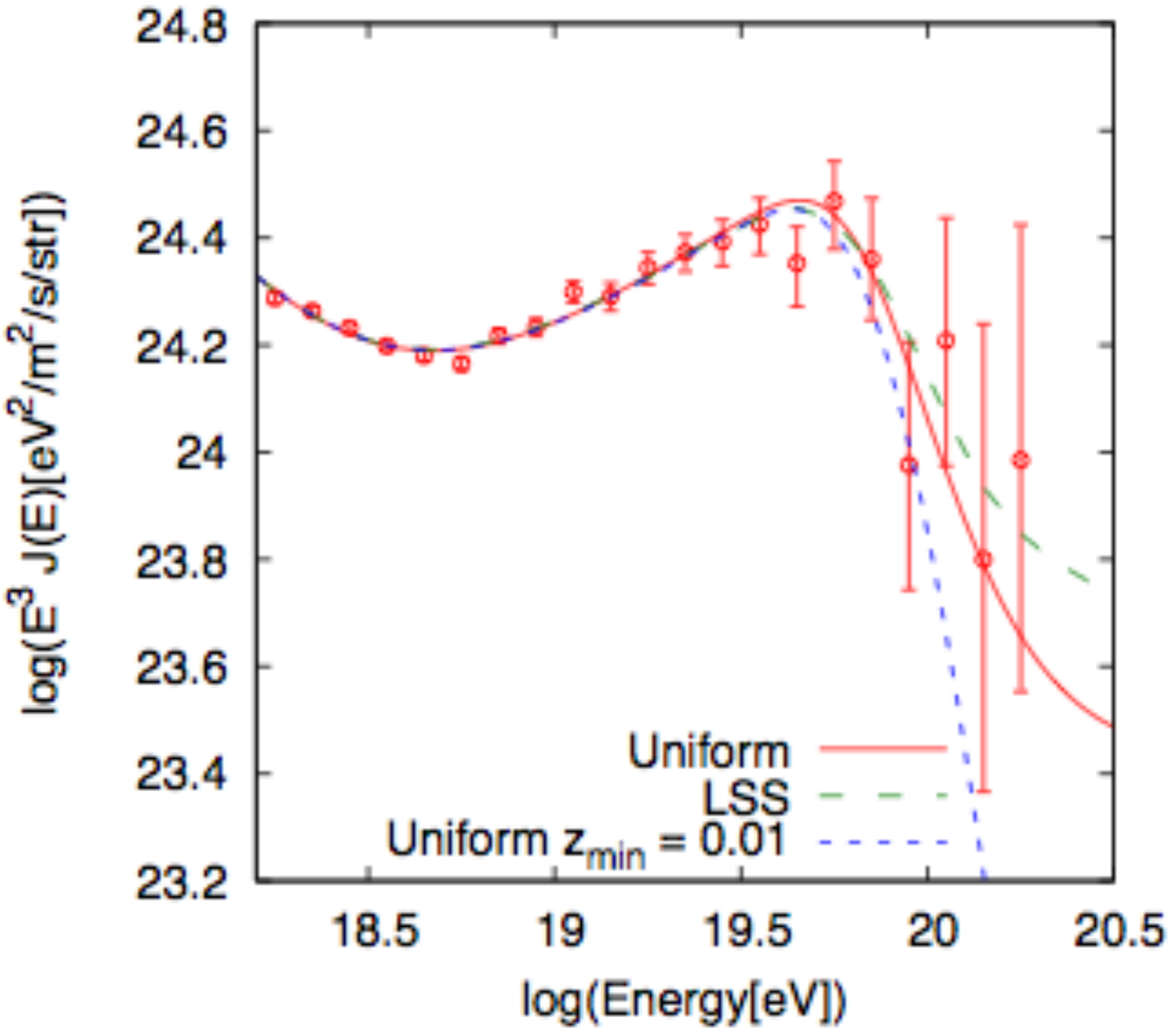
Combined mono spectrum from LR and BRM stations

TA 5-year spectra and extra-galactic proton predictions

p=2.2; m = 6.7 ; E-= 10%

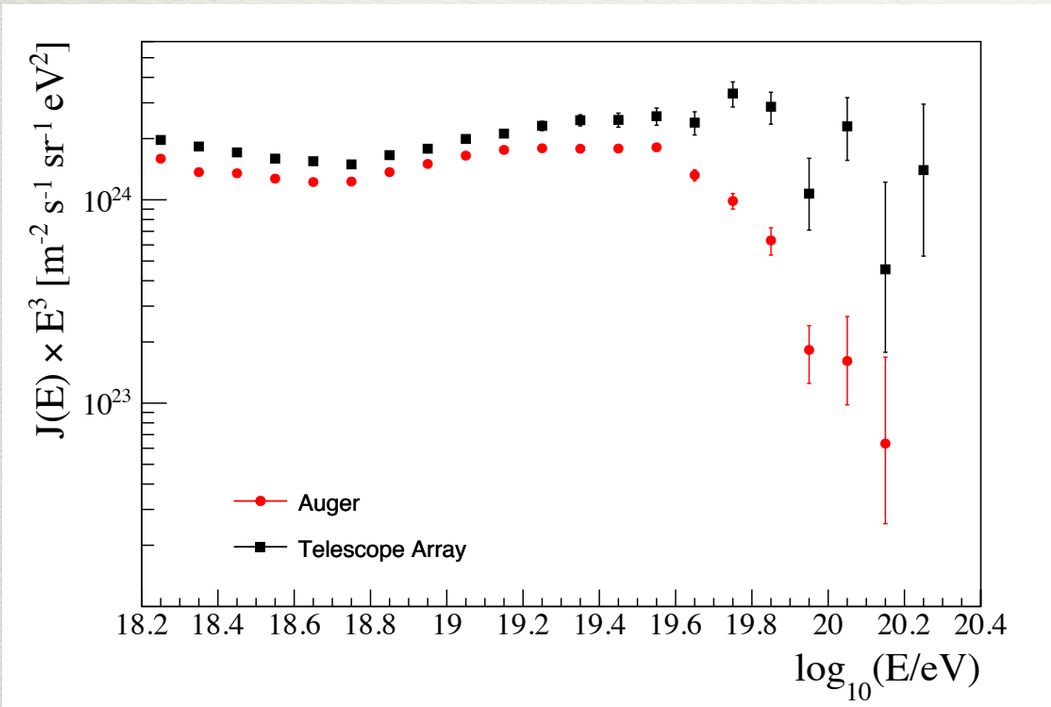
(1+z)^(3+m)

M. Fukushima, arXiv:1503.06961



Comparing

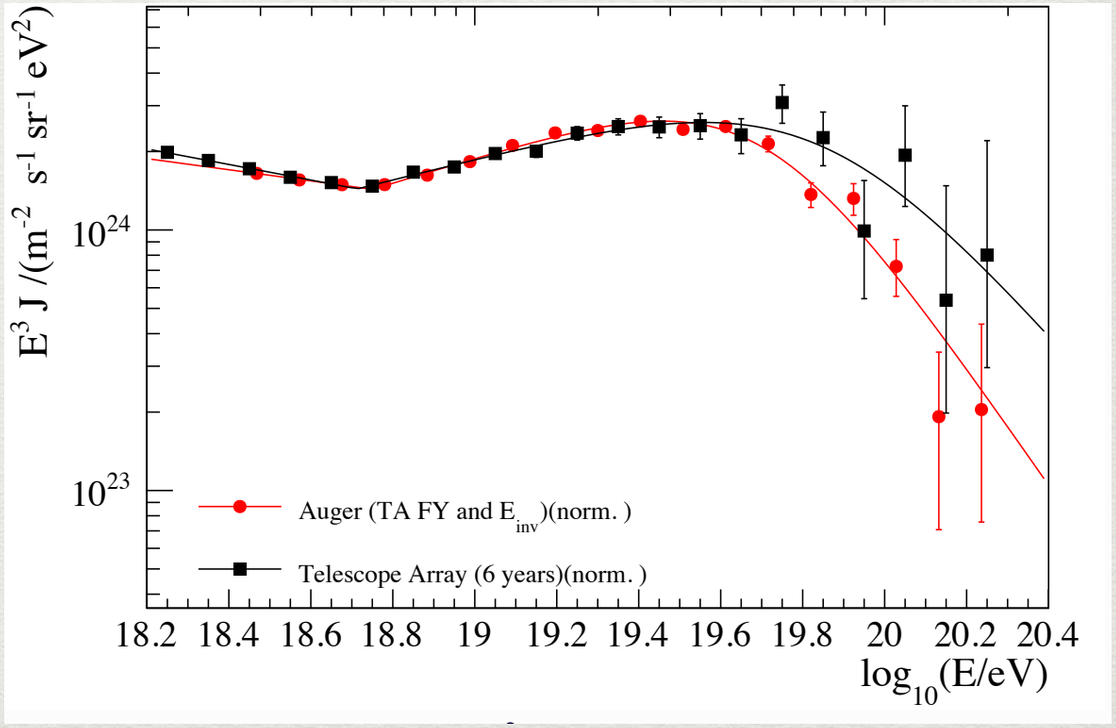
TA coll., ICRC2015 proceedings



- No adjustments

- Adjusting Fluorescence Yield, E scale and normalisation

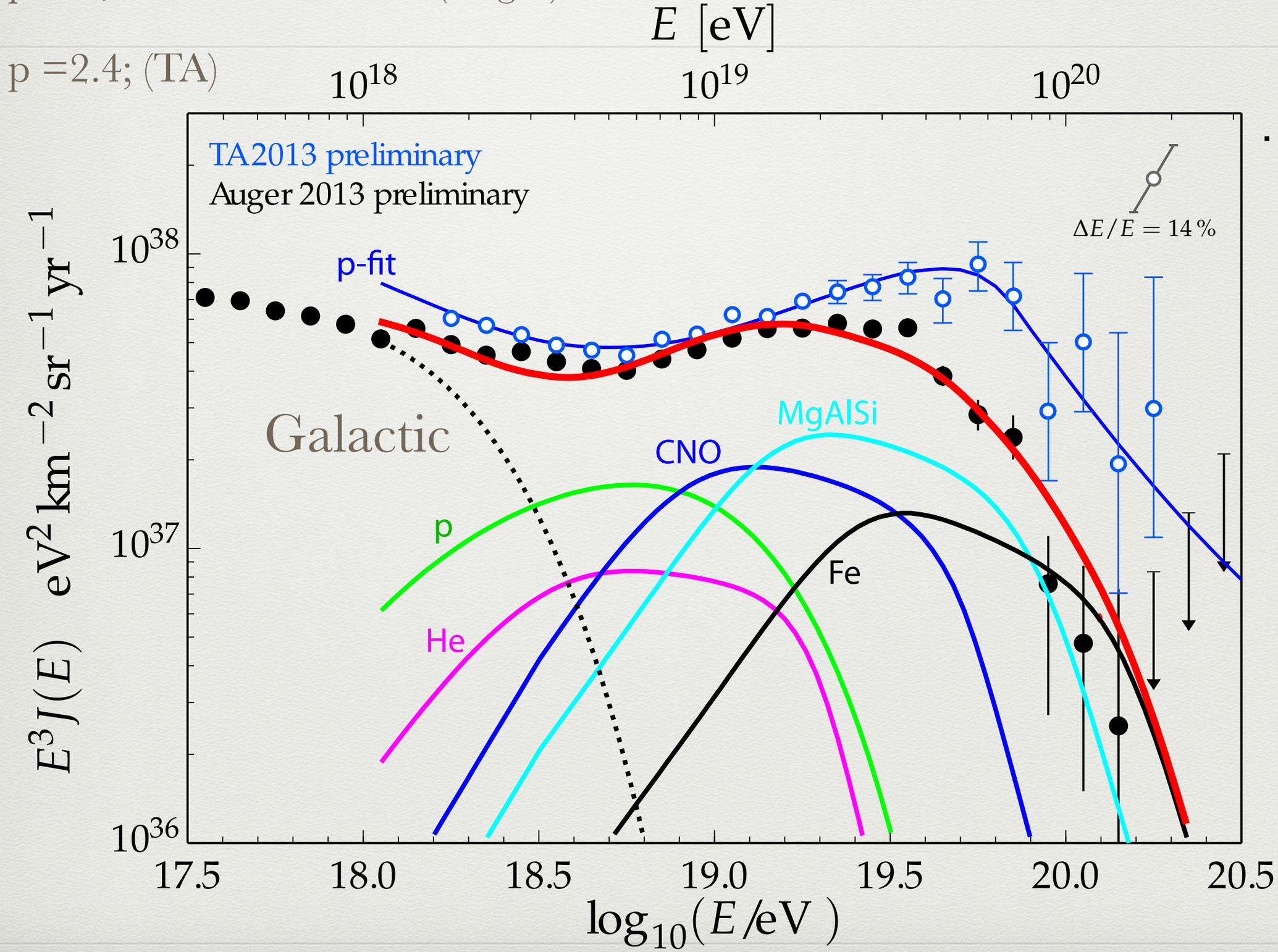
Auger/TA coll., UHECR 2014 symposium, Utah



Kampert & Tinyakov, arXiv 1405.0575

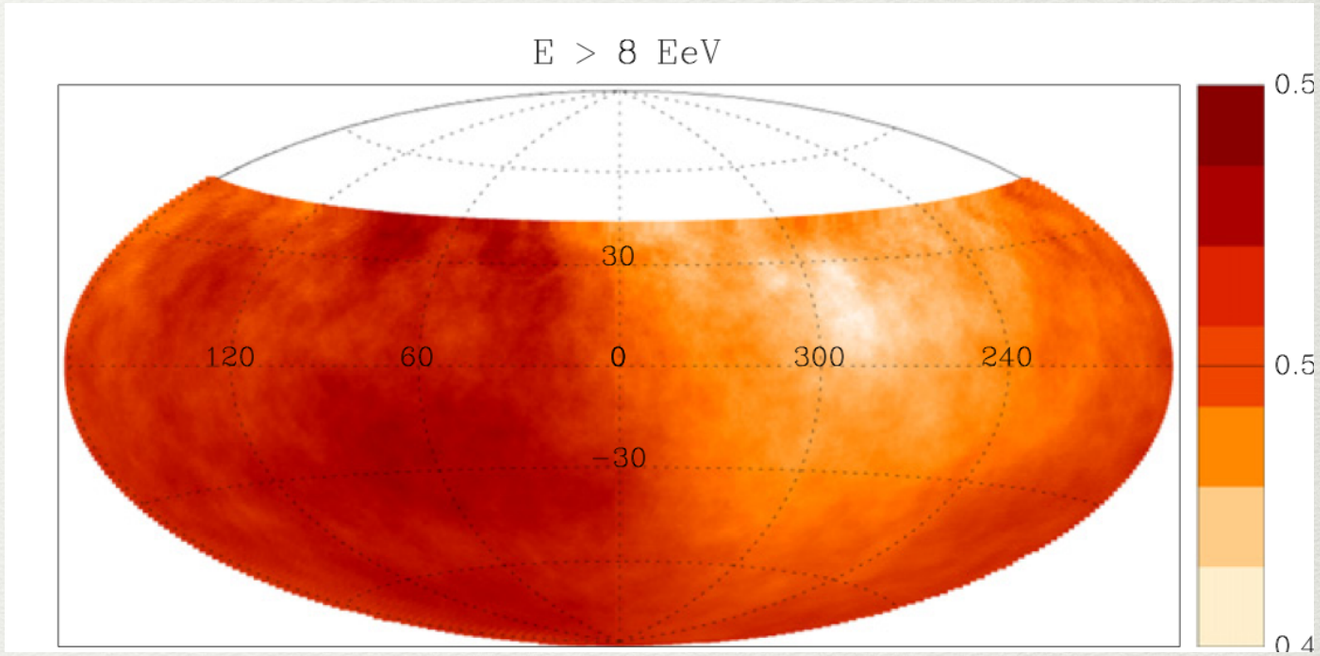
Comparing

- p = 1; Emax = Zx8 EeV (Auger)
- p =2.4; (TA)



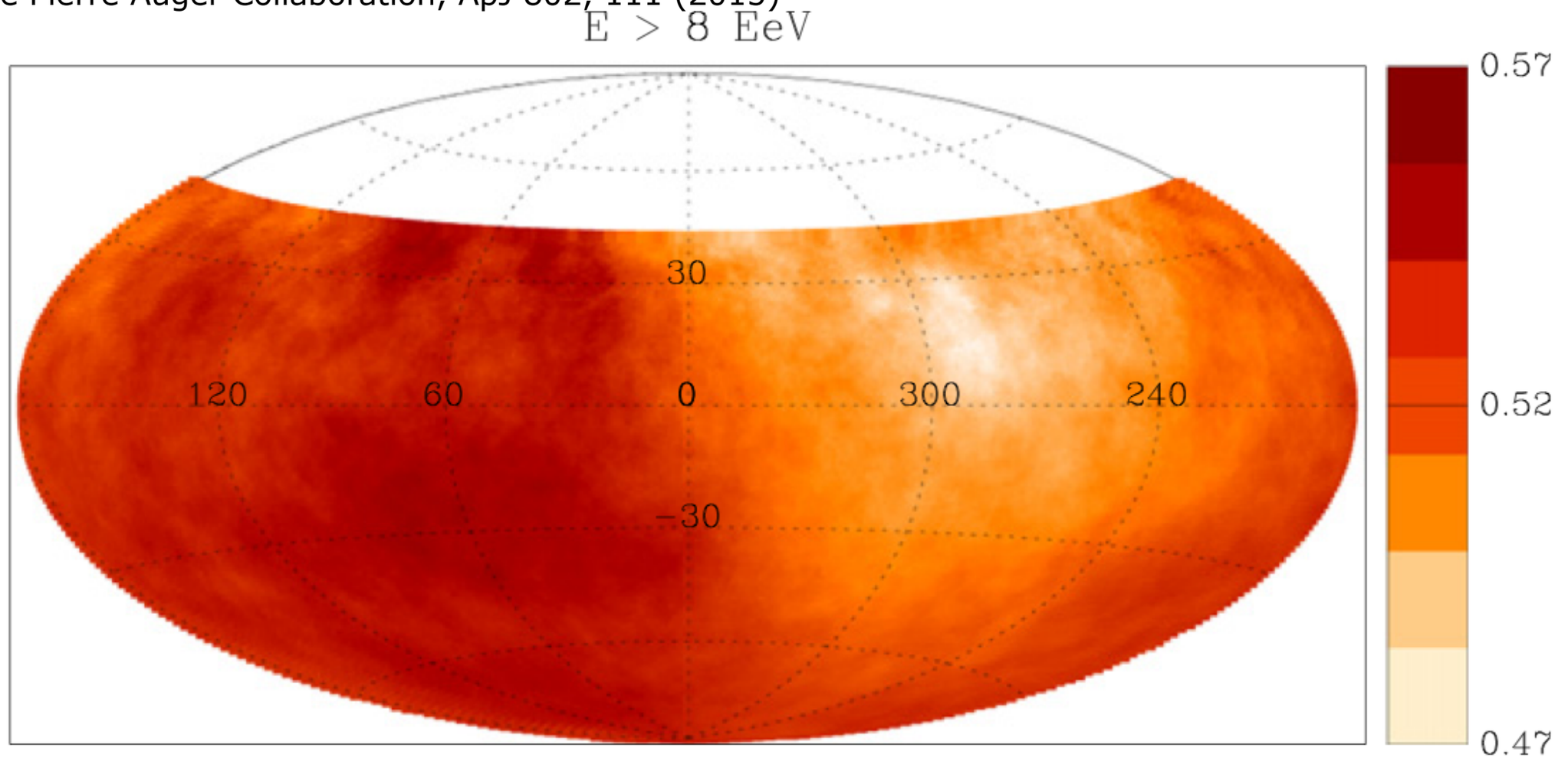
Anisotropies

- Auger From 1 to 10 EeV
- TA+ Auger
- Auger Above 50 EeV
- TA above 50 EeV
- Search for point sources



AUGER
W = 45°, THETA <= 80°

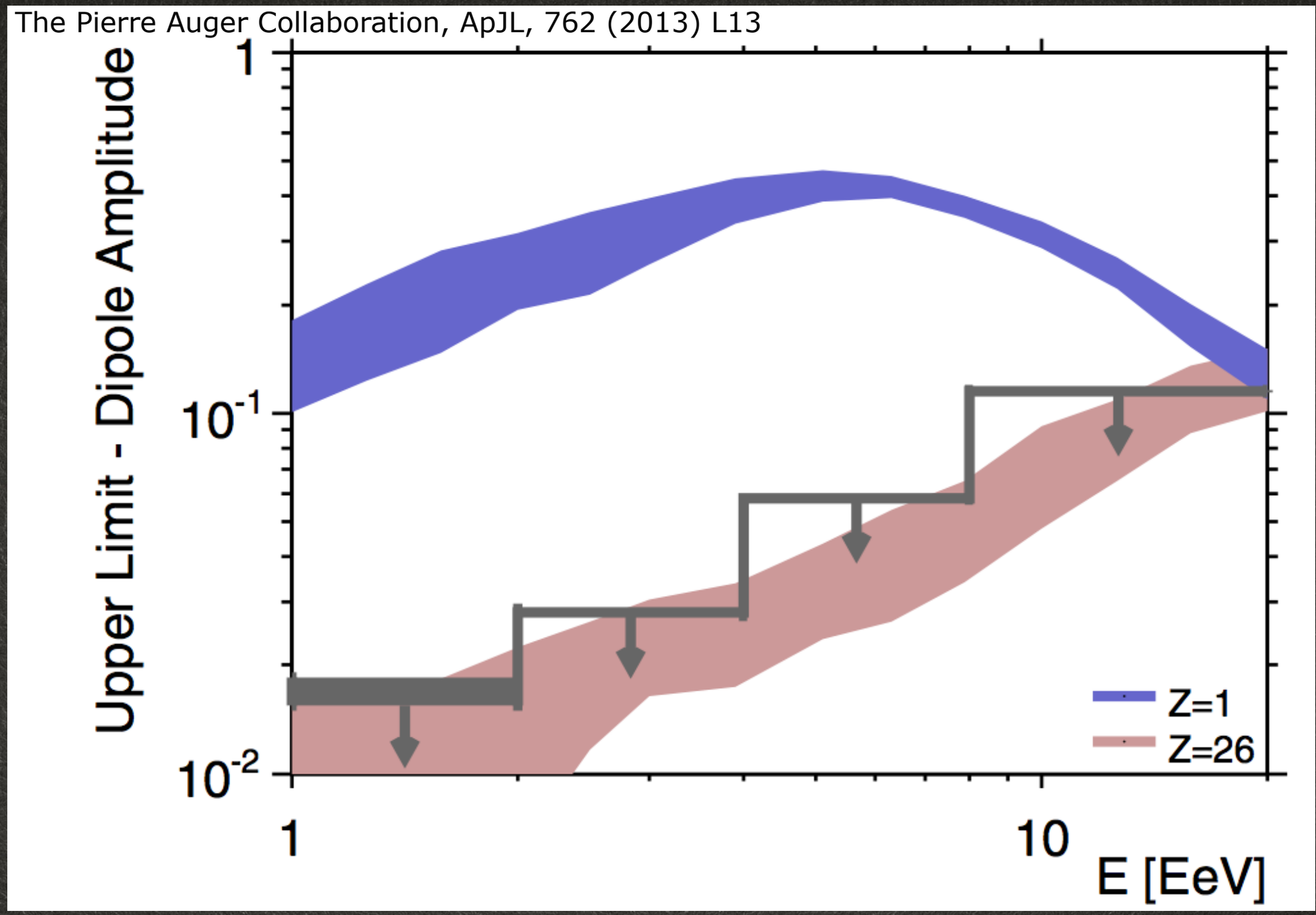
The Pierre Auger Collaboration, ApJ 802, 111 (2015)



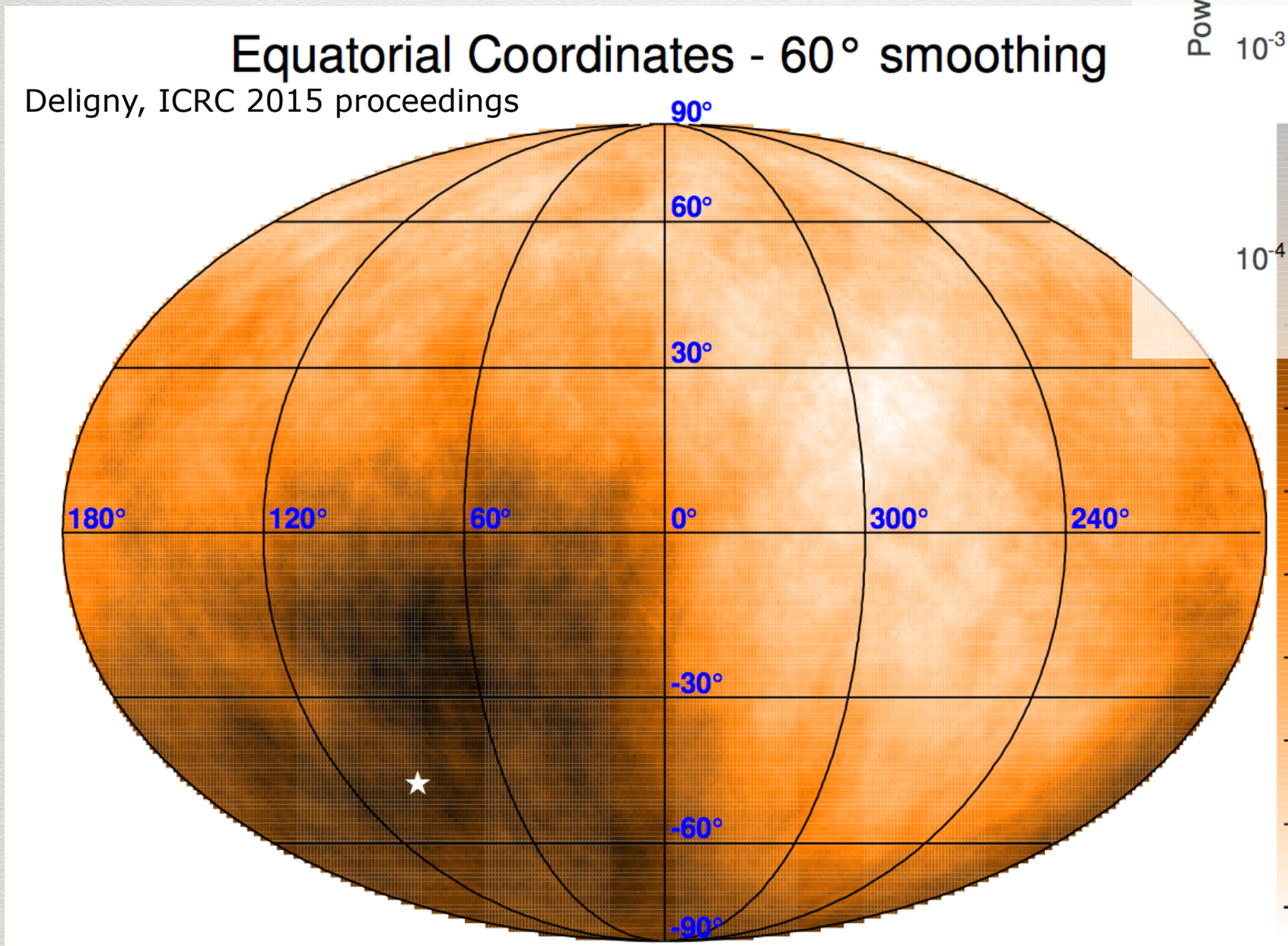
Observations above 8 EeV correspond to a dipole of amplitude
d = 0.073±0.015 pointing to (α, δ) = (95°±13°, -39°±13°).

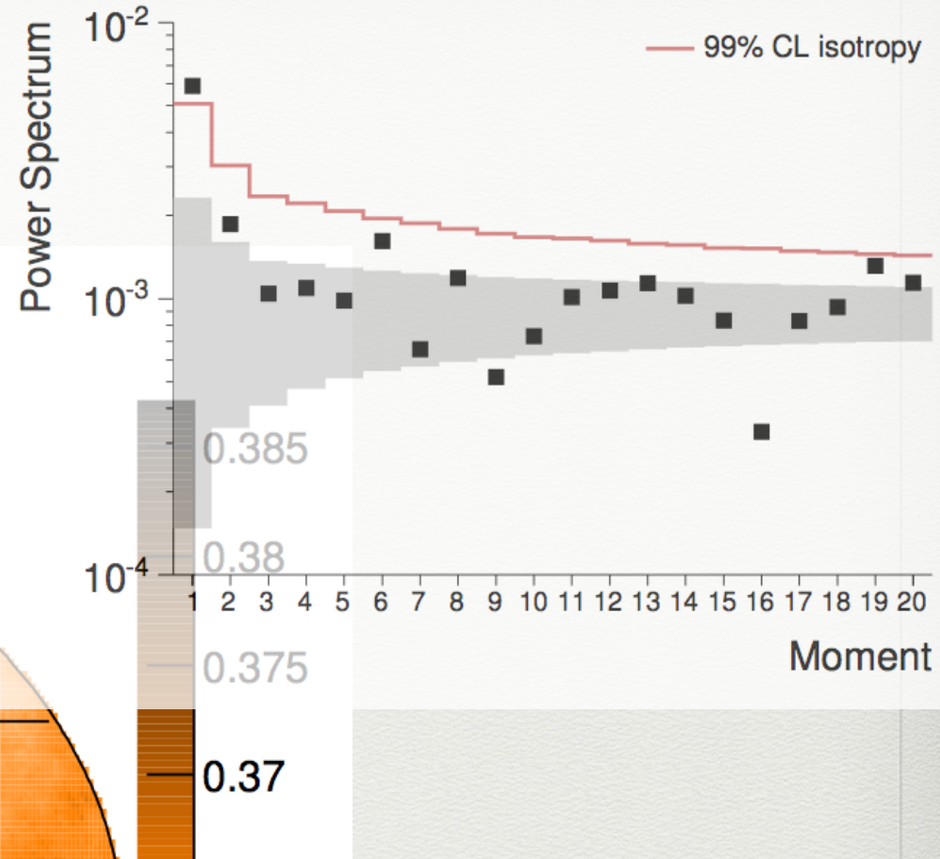
AUGER

The Pierre Auger Collaboration, ApJL, 762 (2013) L13



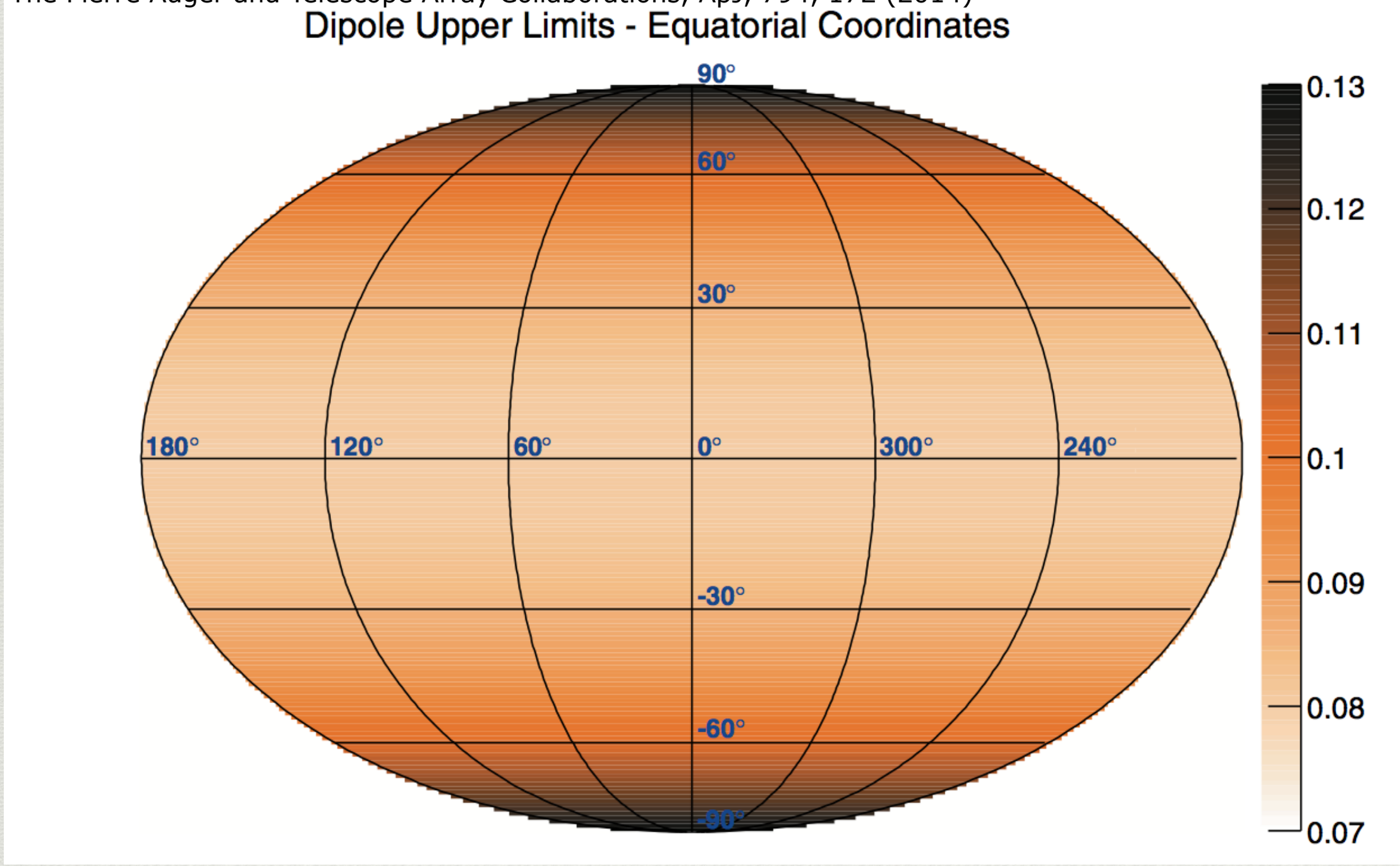
99% CL upper limits on dipole amplitudes as a function of the energy. Some generic anisotropy expectations from stationary galactic sources distributed in the disk are shown, for two assumptions on the cosmic ray composition. The fluctuations of the amplitudes due to the stochastic nature of the turbulent component of the magnetic field are sampled from different simulation data sets and are shown by the bands.





Auger and TA above 10 EeV
The dipole amplitude is observed to be (6.5 ± 1.9)%
with a chance probability of 5 × 10−3 ,
pointing to (93º ± 24) in right ascension and (−46º ± 18) in declination.

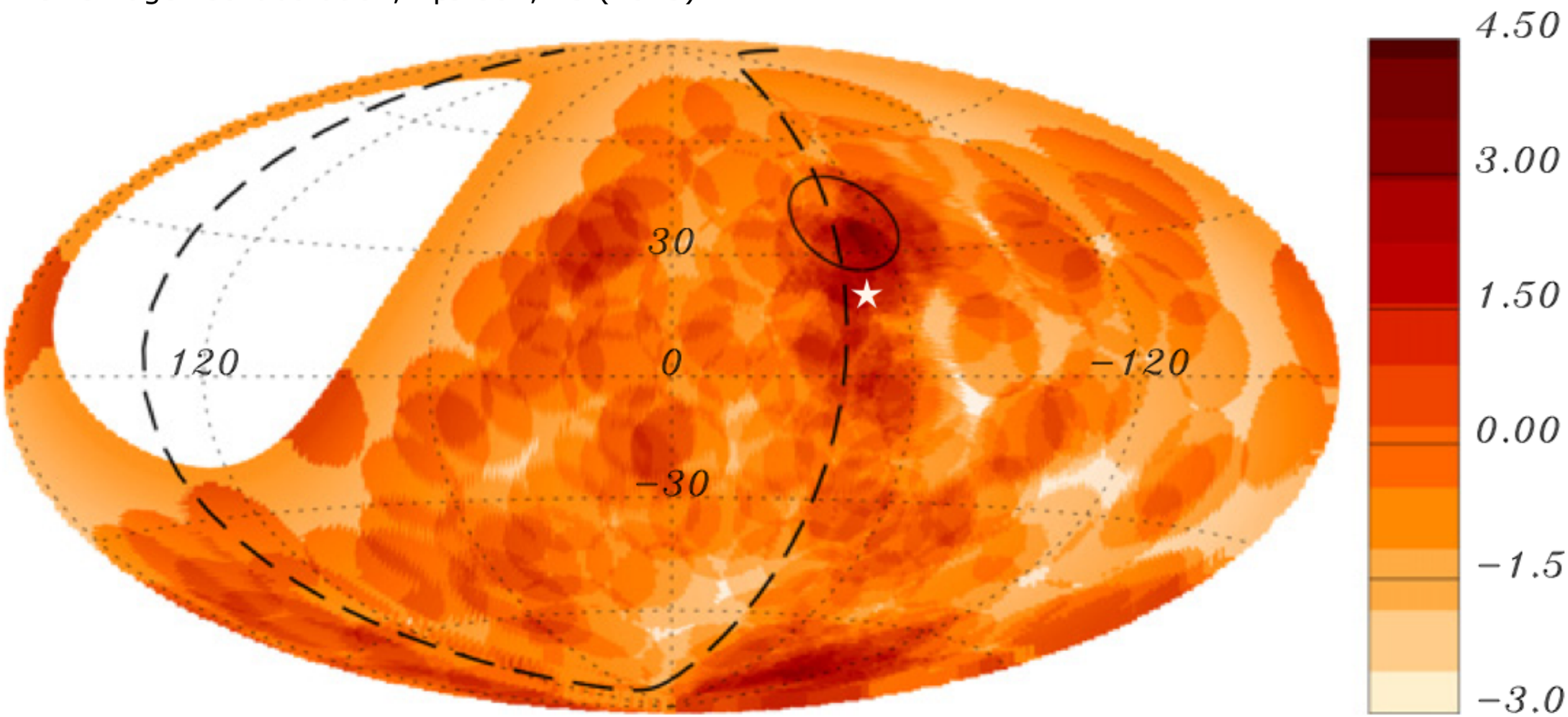
The Pierre Auger and Telescope Array Collaborations, ApJ, 794, 172 (2014)



99% confidence level upper limits on the dipole amplitude as a function of the latitude and longitude, in Equatorial coordinates and Mollweide projection

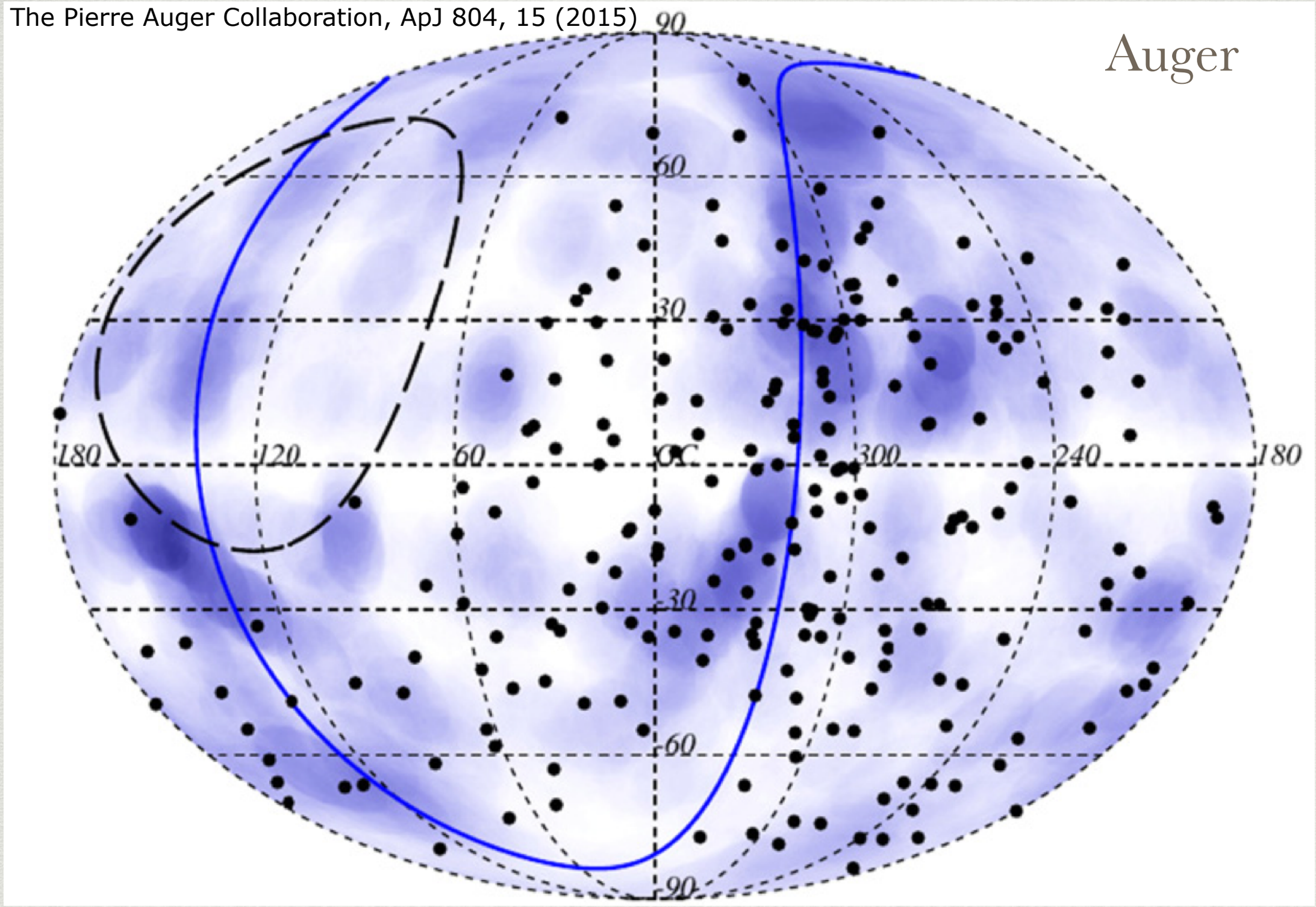
Auger above 50 EeV

The Pierre Auger Collaboration, ApJ 804, 15 (2015)



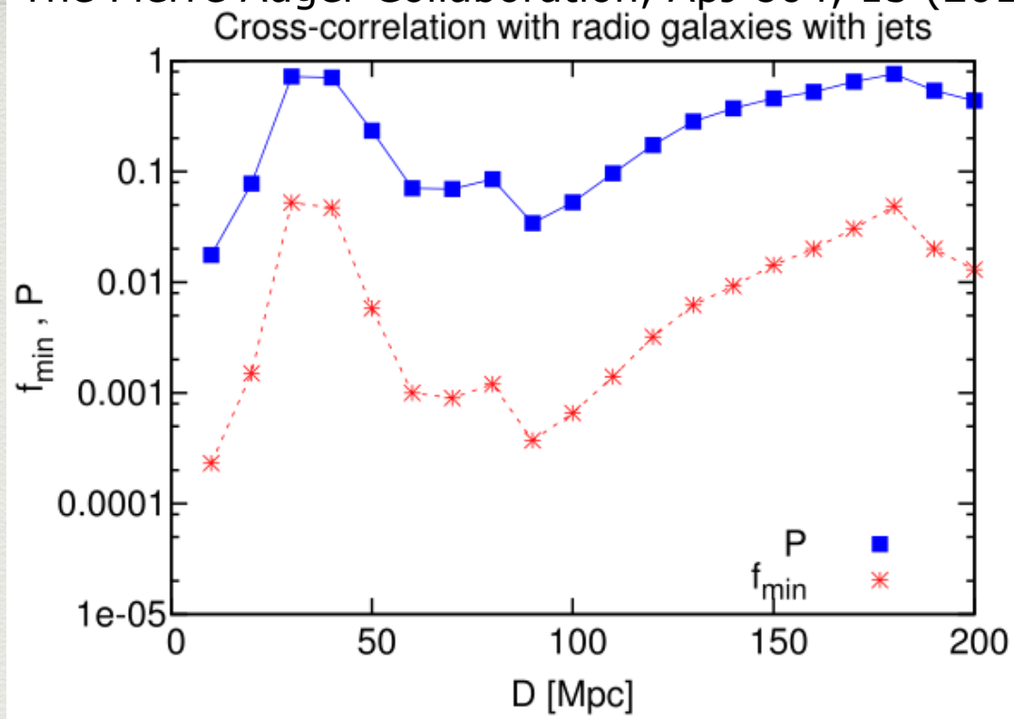
Map in Galactic coordinates of the Li–Ma significances of over densities in 12°-radius windows for the events with E ≥ 54 EeV. Also indicated are the Super-Galactic Plane (dashed line) and Centaurus A (white star).

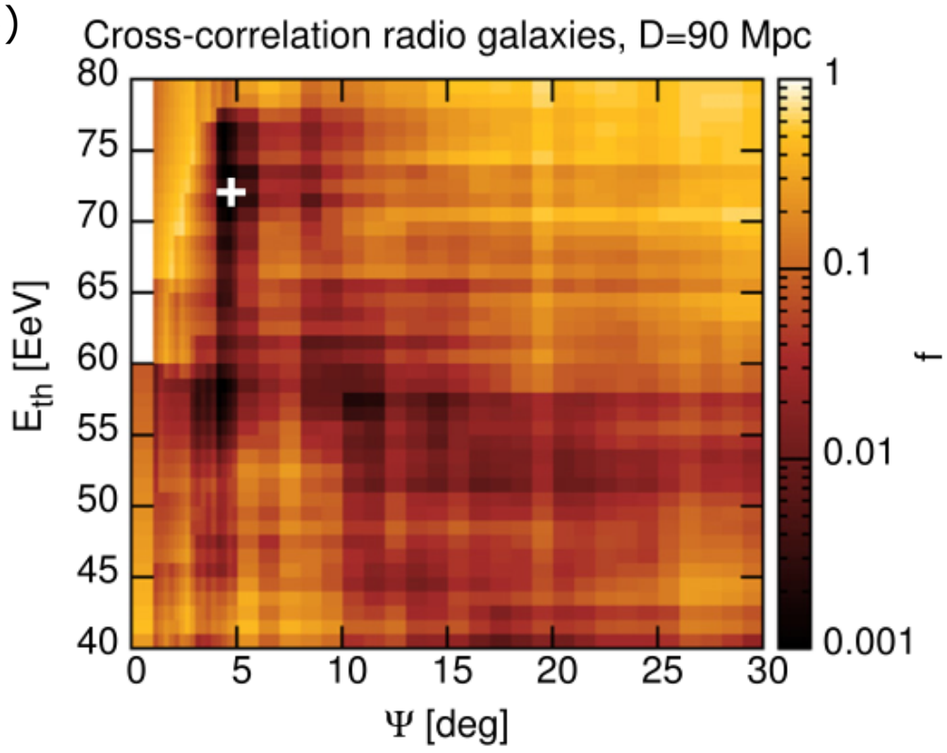
The Pierre Auger Collaboration, ApJ 804, 15 (2015)

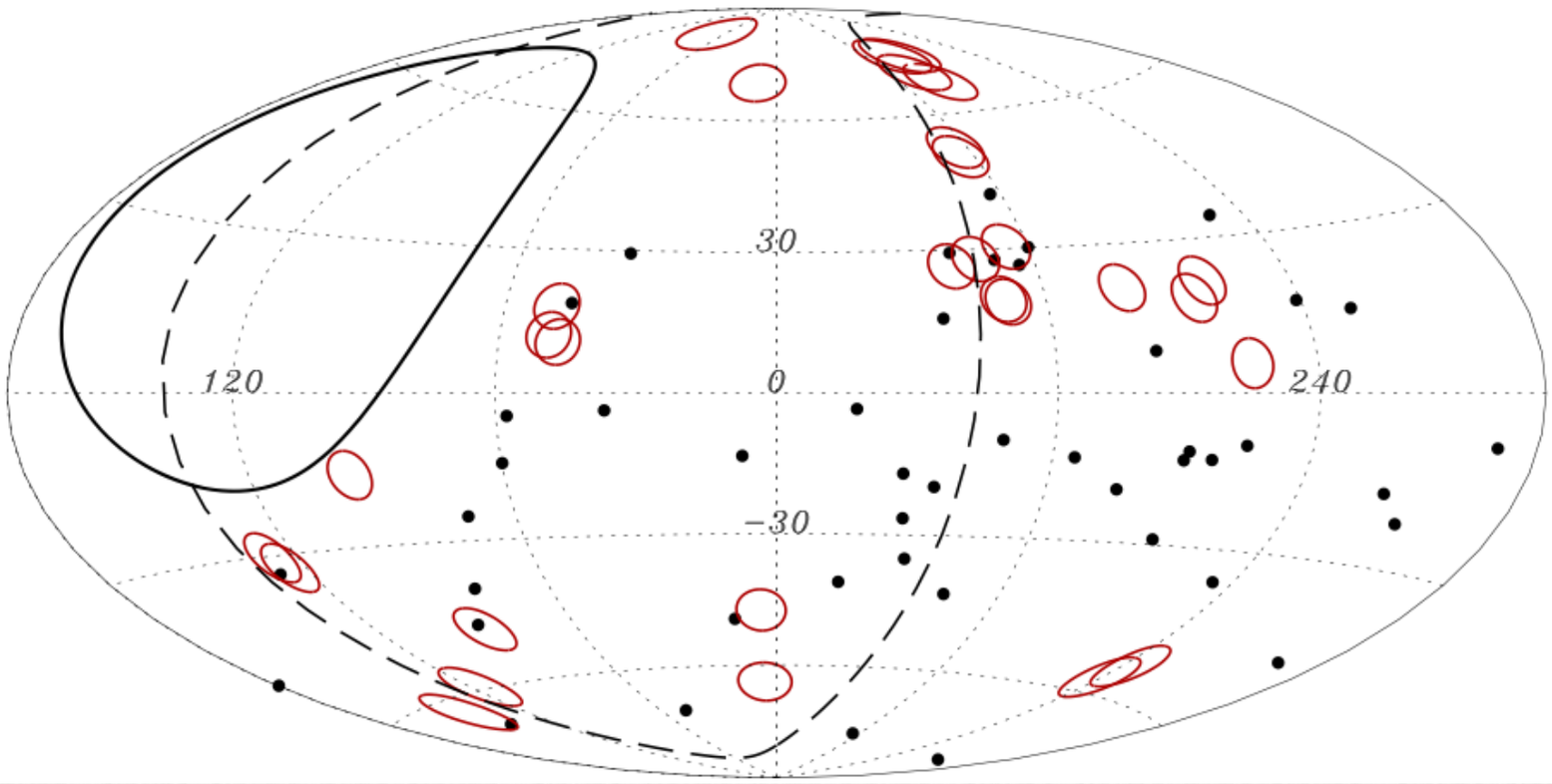


Sky distribution (in Galactic coordinates) of the events with $E \geq 52$ EeV (black dots). Blue fuzzy circles of 9° radius around all of the 2MRS objects closer than 90 Mpc.

The Pierre Auger Collaboration, ApJ 804, 15 (2015)

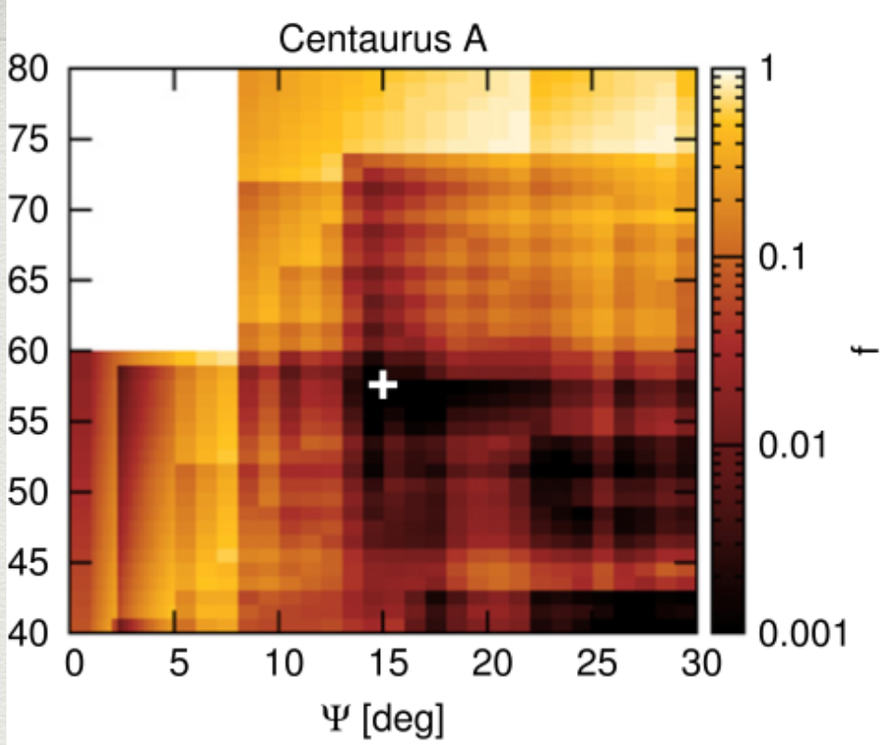


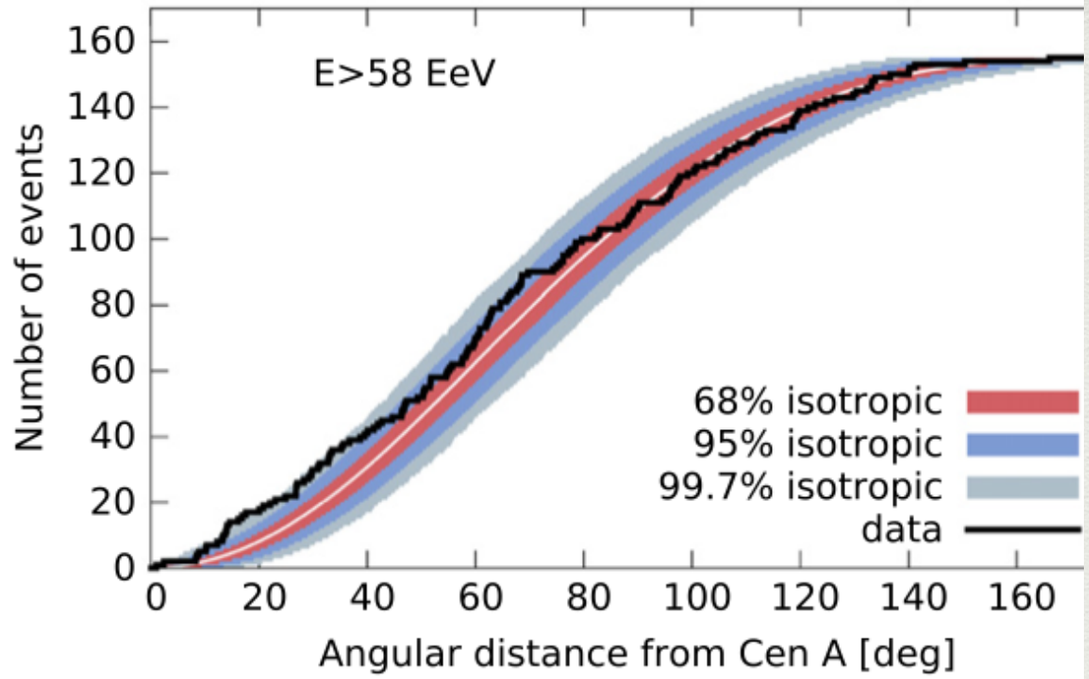


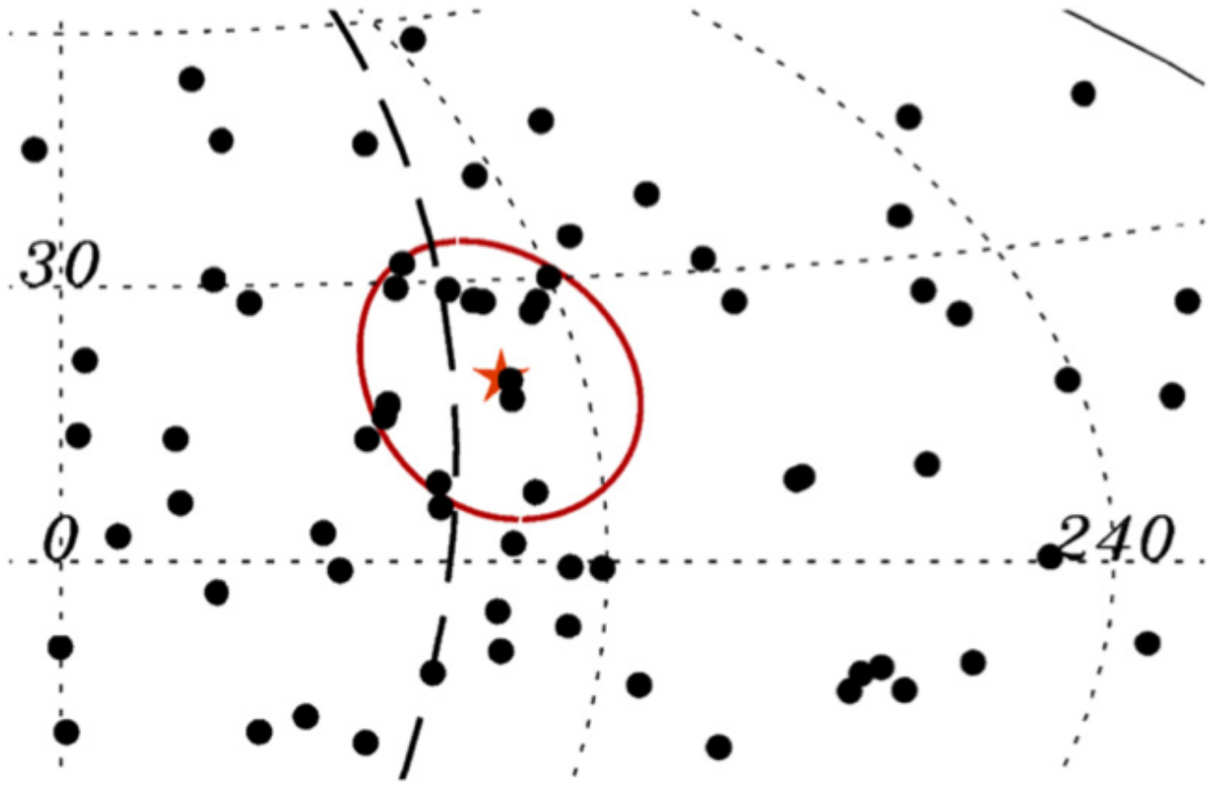


Cross-correlation of events with the AGNs in the catalog of radio galaxies with jets. The top-left panel shows the values of fmin and P as a function of the maximum distance, D, to the AGNs considered. The top-right panel shows the results of the scan in ψ and Eth for the value D = 90 Mpc corresponding to the (second) minimum in the top-left plot. The bottom plot shows the sky distribution (in Galactic coordinates) of the events with E ≥ 72 EeV (black dots). Red circles of 4º.75 radius are drawn around the radio galaxies closer than 90 Mpc.

The Pierre Auger Collaboration, ApJ 804, 15 (2015)

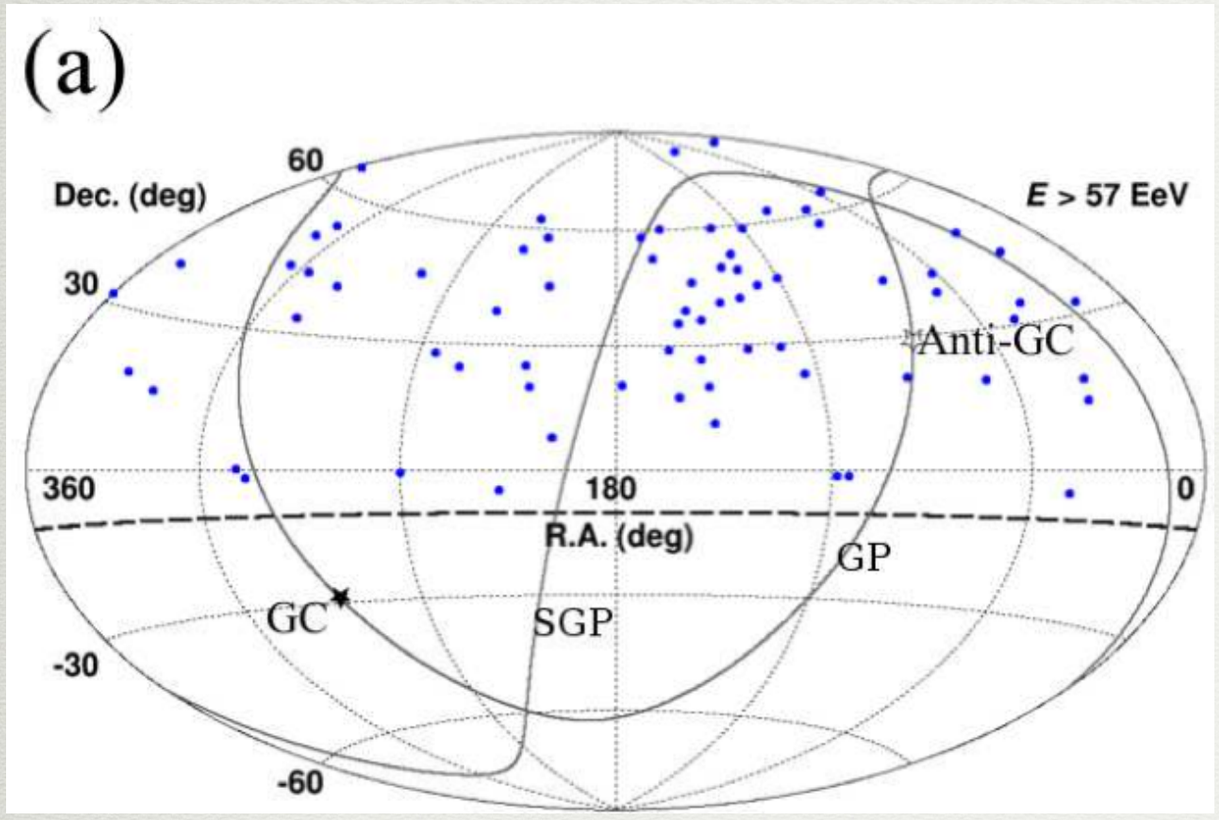


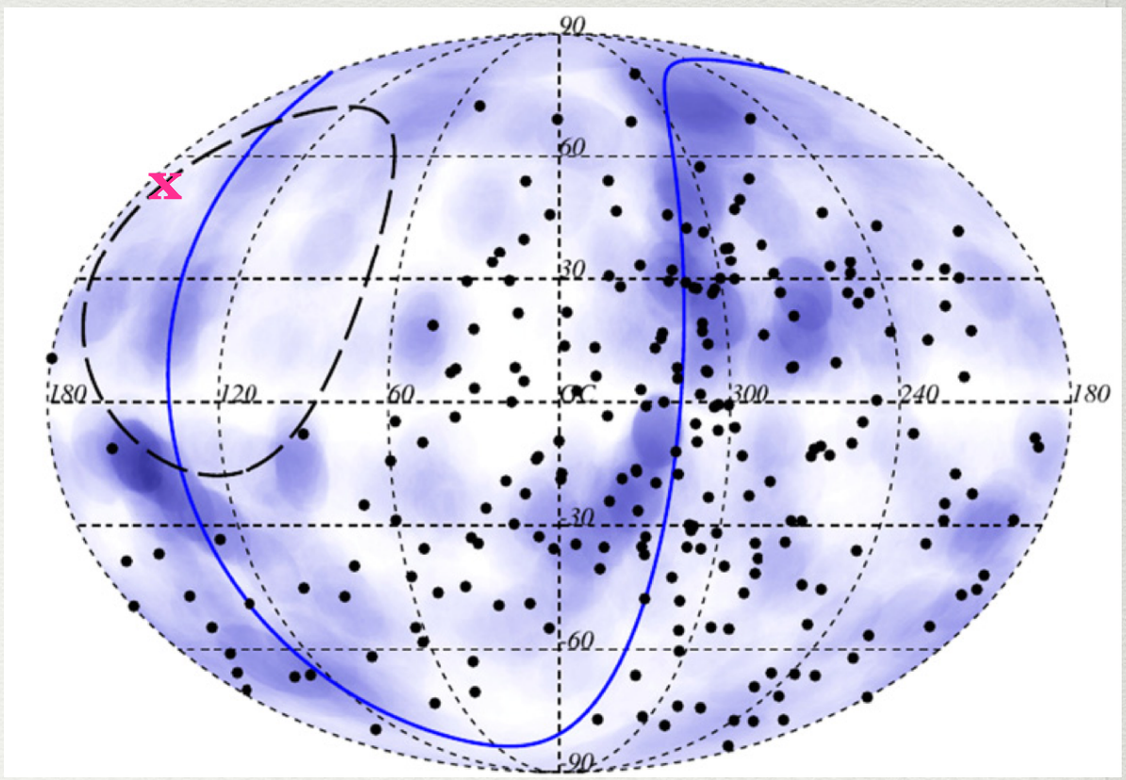




Correlation of events with the Cen A radio galaxy as a function of the angular distance and the energy threshold, Eth (top-left panel). The top-right panel shows the cumulative number of events for the threshold Eth = 58 EeV, exploring the whole angular range. The bottom panel displays the map (in Galactic coordinates) of the region around Centaurus A, showing the arrival directions of the events with E ≥ 58 EeV (black dots) and a red circle of 15° radius around the direction of Cen A, indicated by a star.

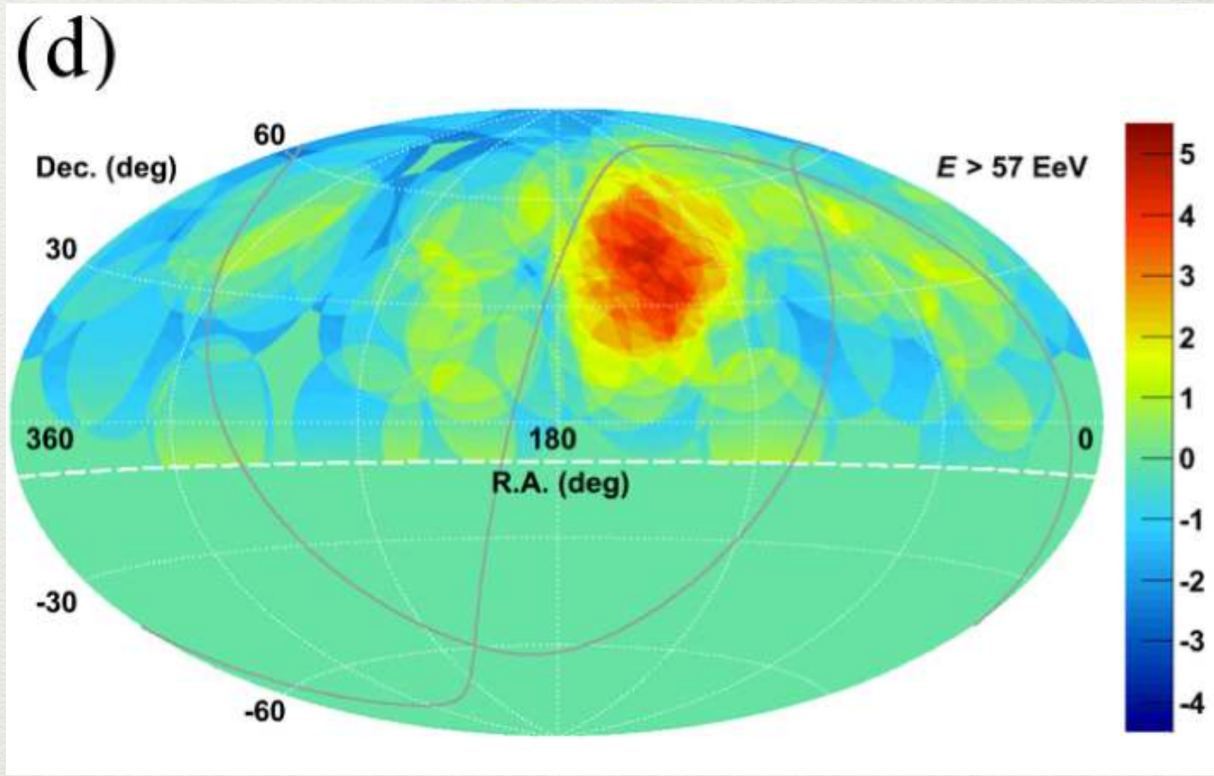
TA event map above 57 EeV



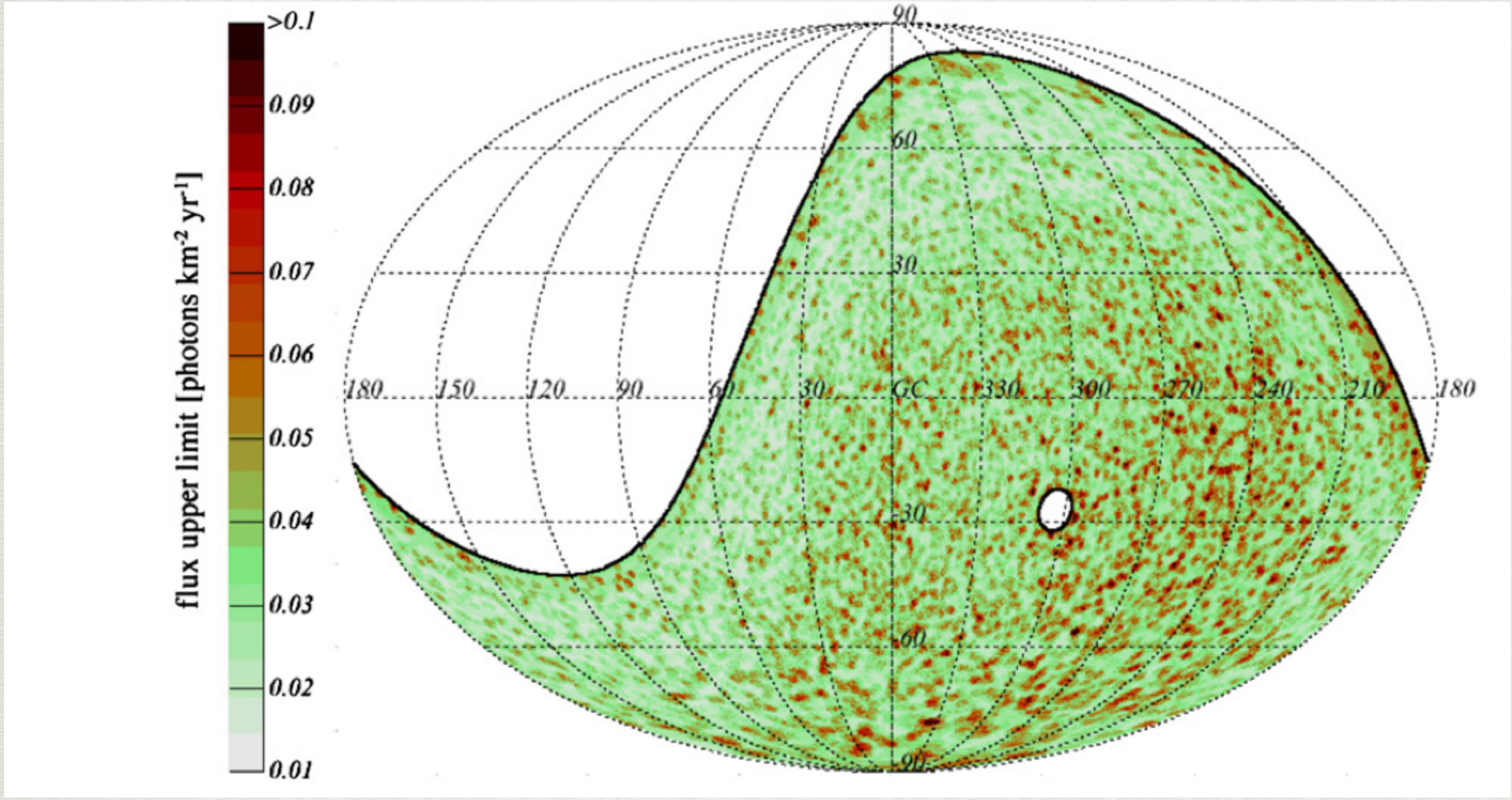


The TA Collaboration, arXiv:1404.5890

significance map above 57 EeV
p = 0,037% (3.4σ)
RA=146°.7, Dec = 43°.2
Gal. Lon = 177°.4, Lat = 50°.2



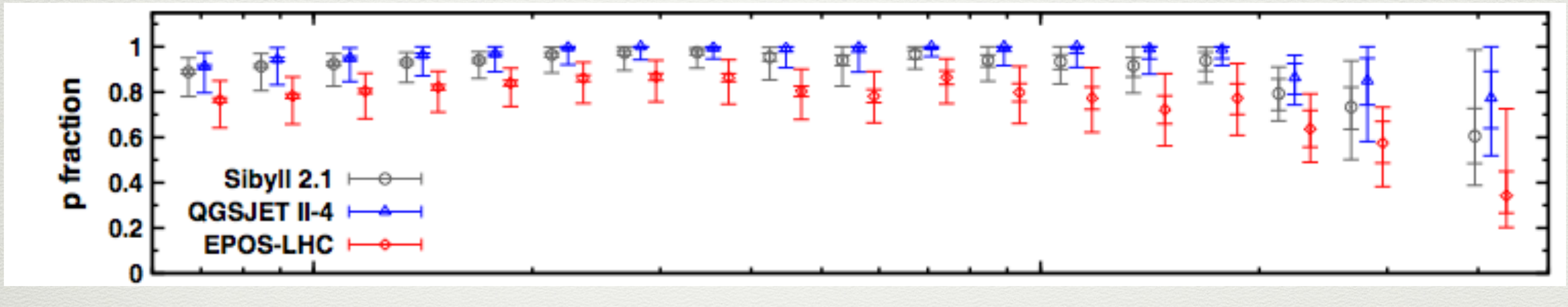
The Pierre Auger Collaboration, ApJ, 789 (2014) 160



Celestial map of photon flux upper limits in photons km−2 yr−1 illustrated in Galactic coordinates.

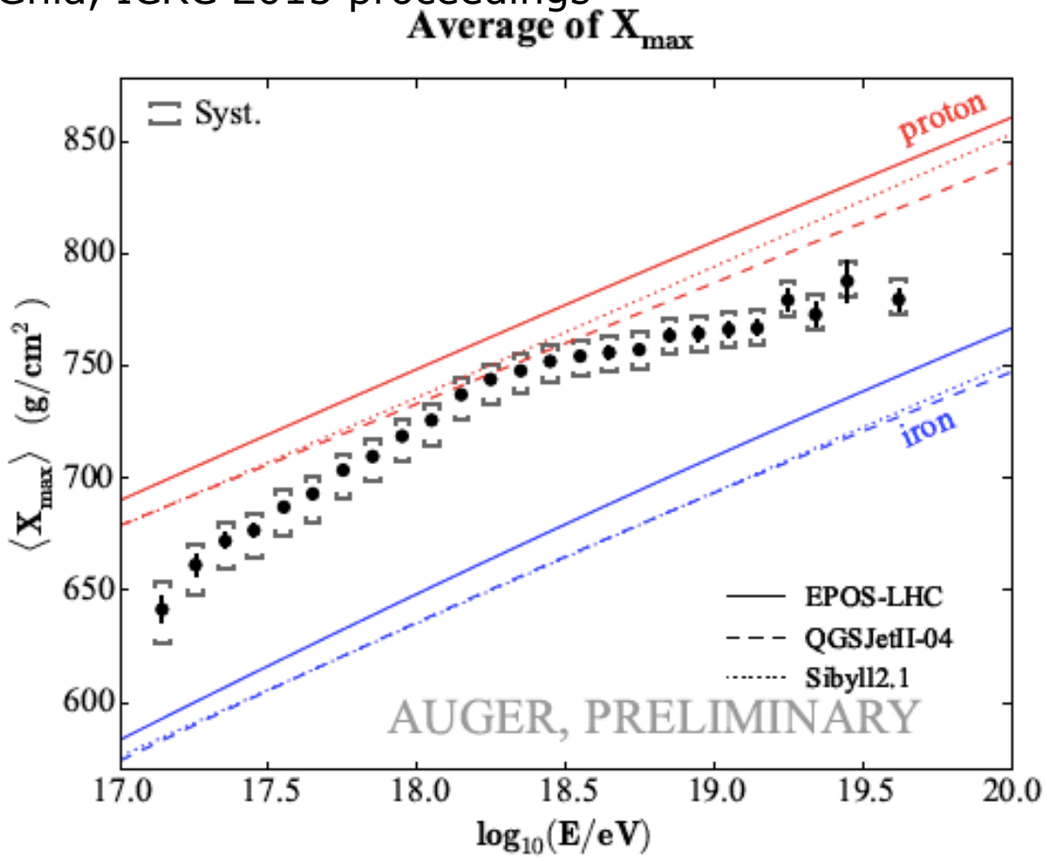
A search for targeted EeV neutron sources gave null results as well

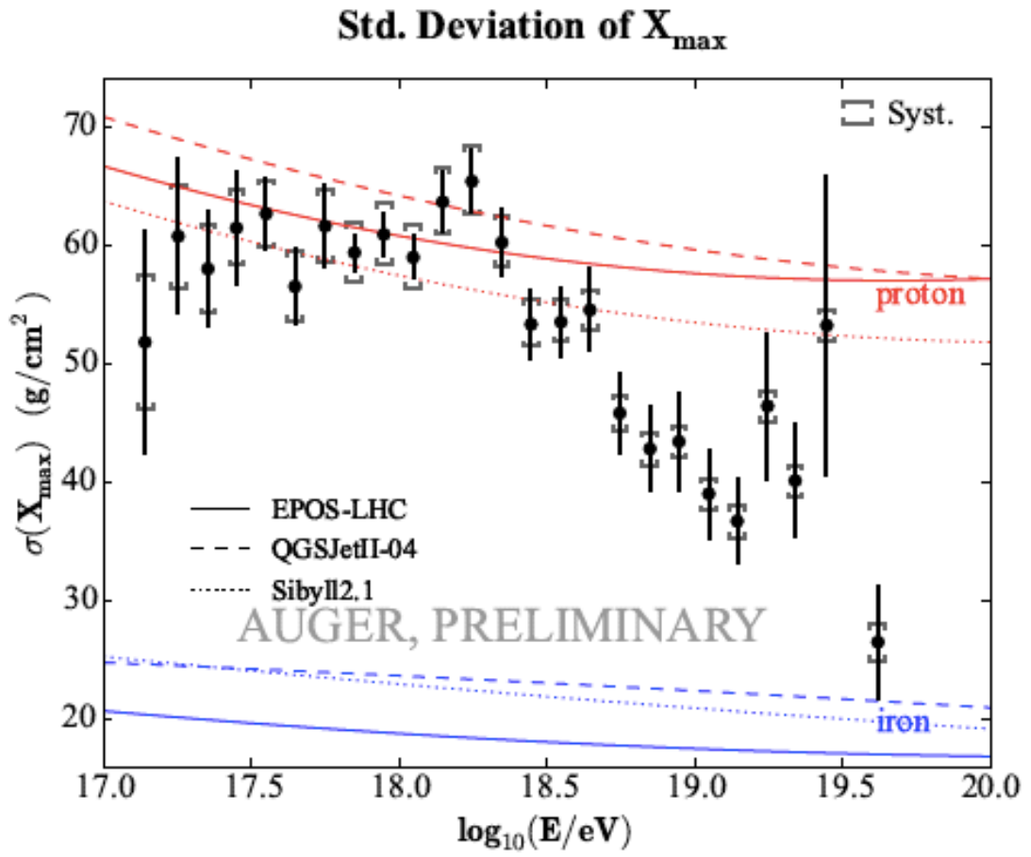
Mass composition



- Auger
- TA
- comparison

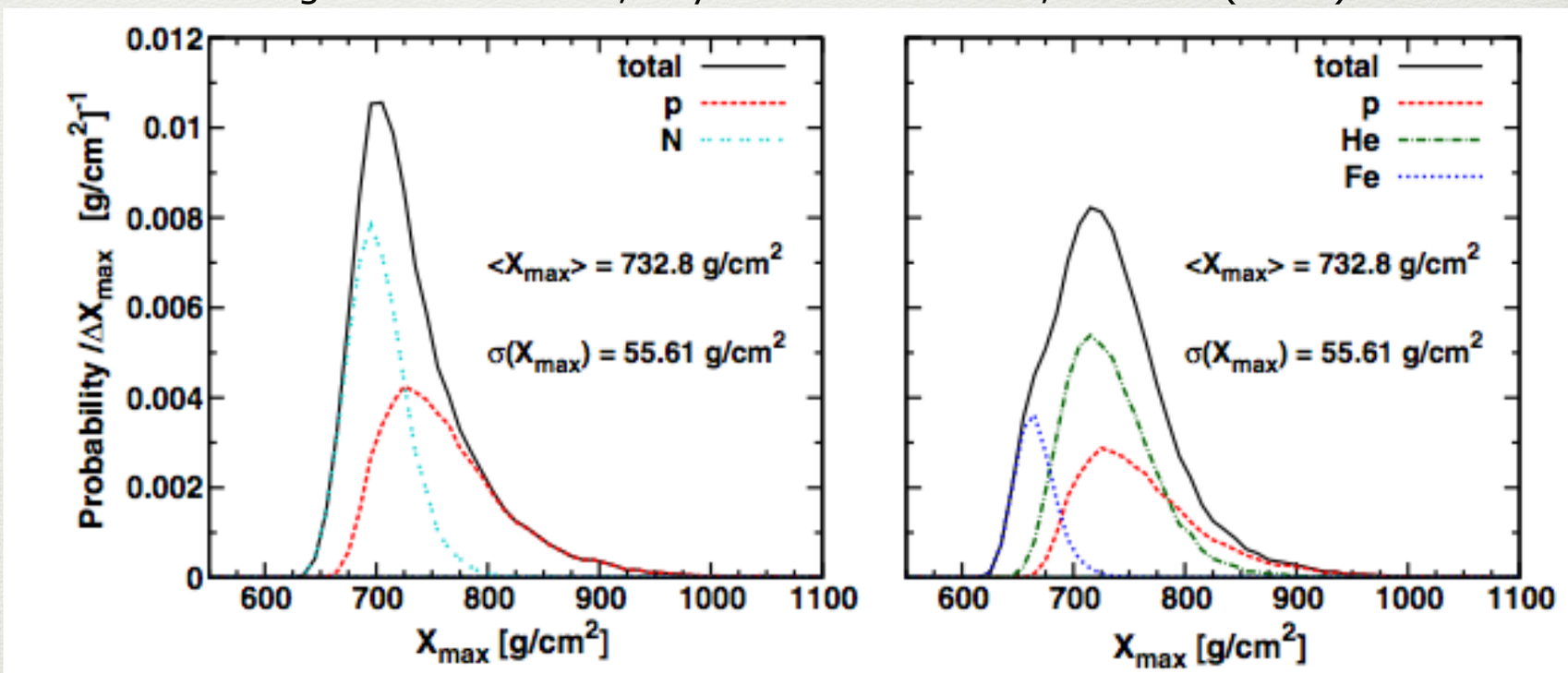
P. Ghia, ICRC 2015 proceedings



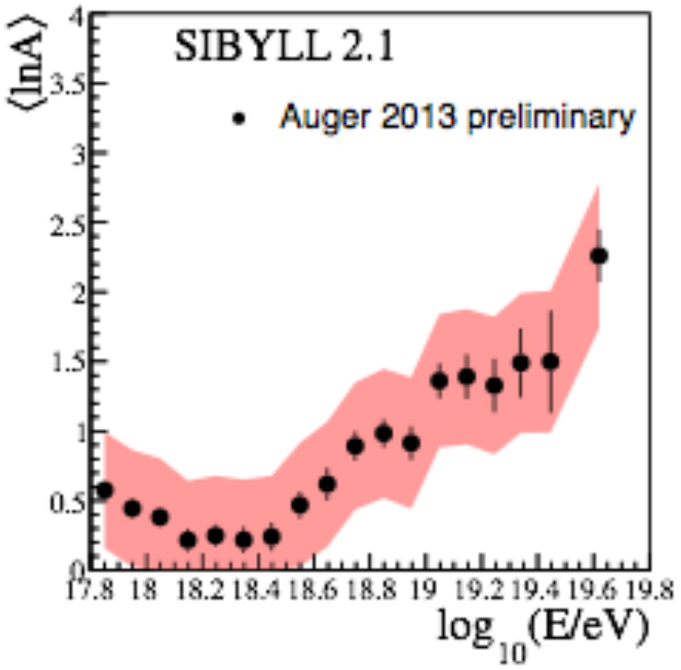


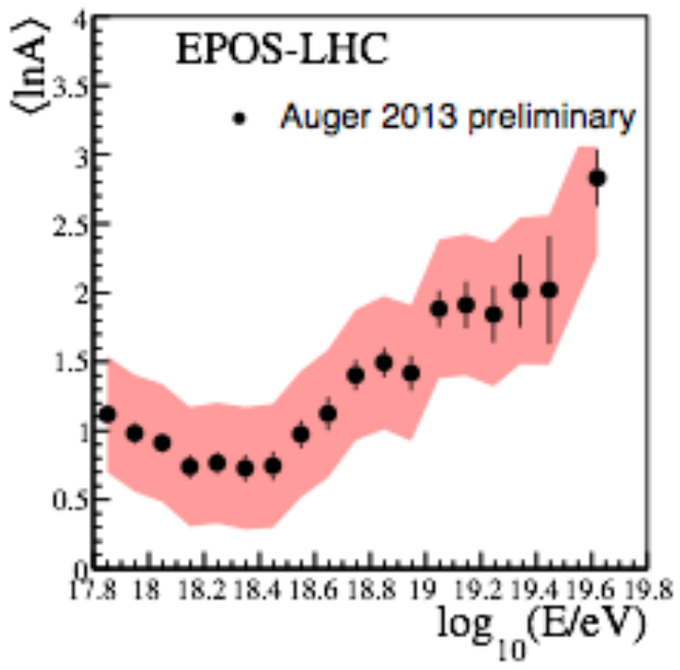
Evolution of ⟨Xmax⟩ and σXmax as a function of energy. Measurements are from the hybrid data set of Auger.

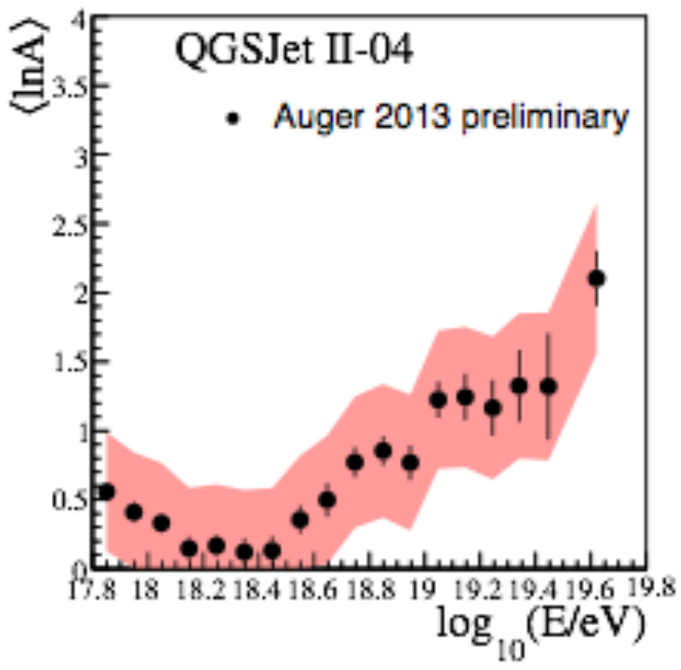
The Pierre Auger Collaboration, Physical Review D 90, 122005 (2014)

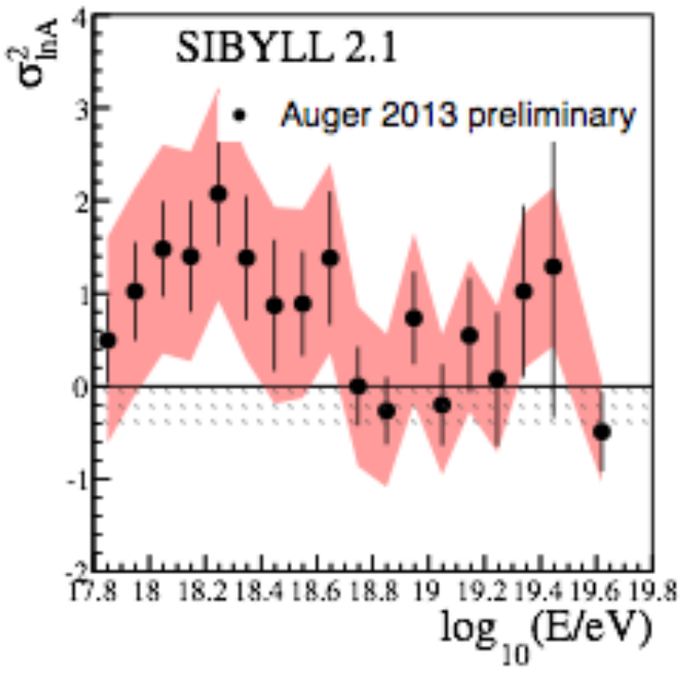


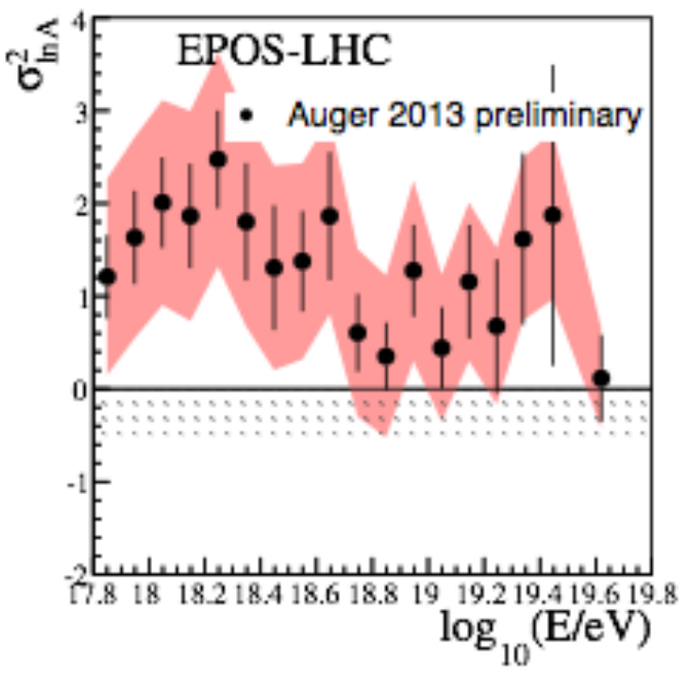
ALS, 33rd ICRC, arXiv:1310.4620

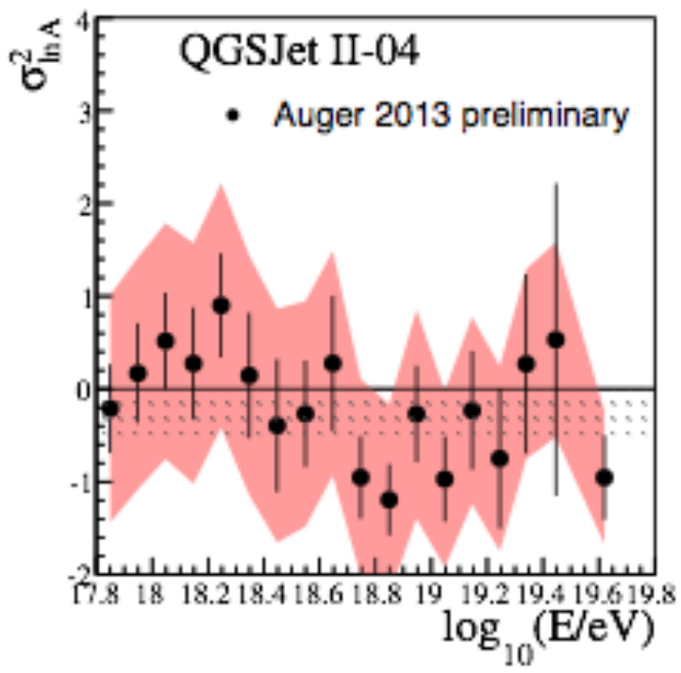


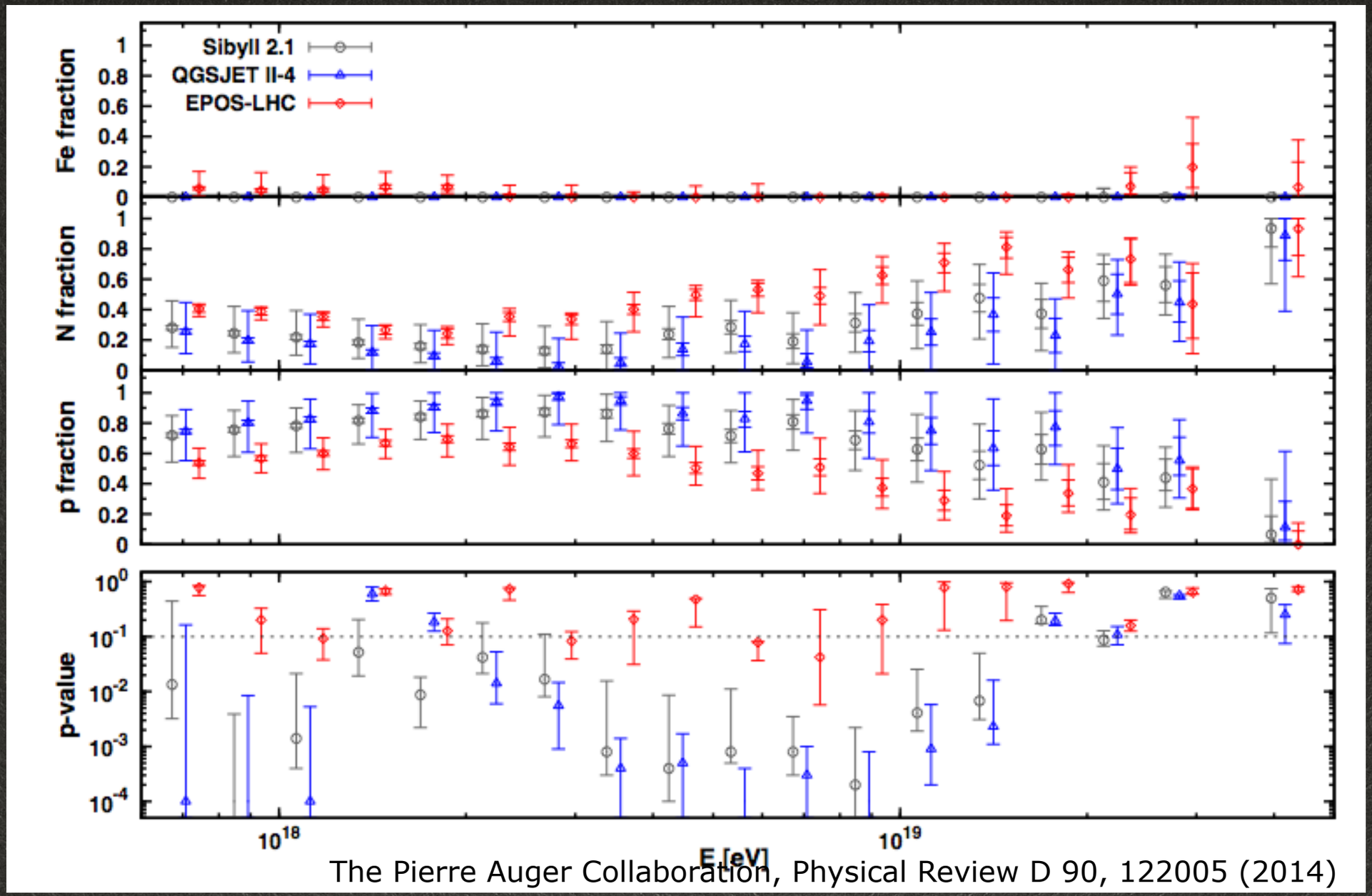






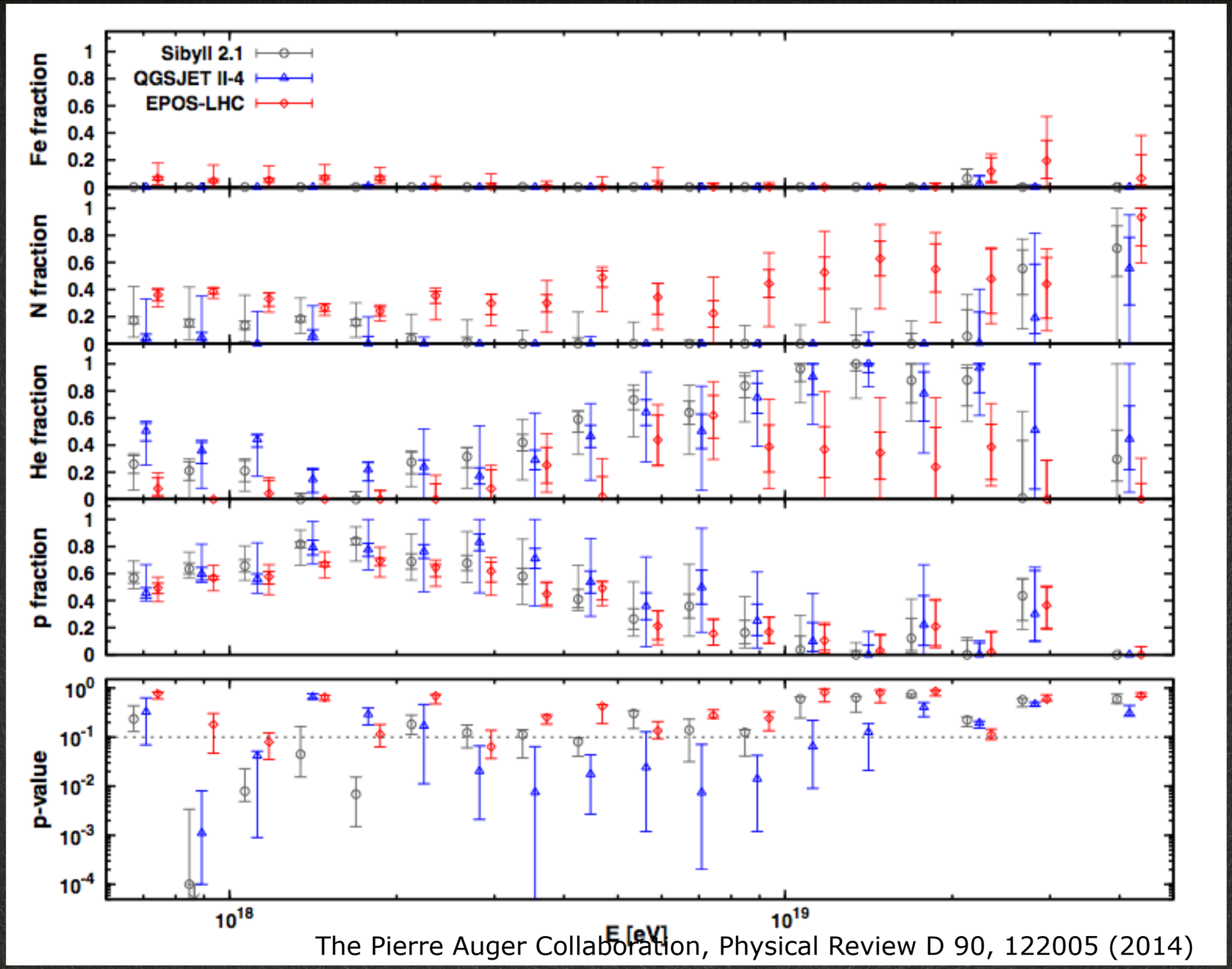






The Pierre Auger Collaboration, Physical Review D 90, 122005 (2014)

Fitted fraction an quality for a scenario with a mixture of proton, nitrogen and iron nuclei. The upper panels show the species fractions and the lower panel shows the p-values.

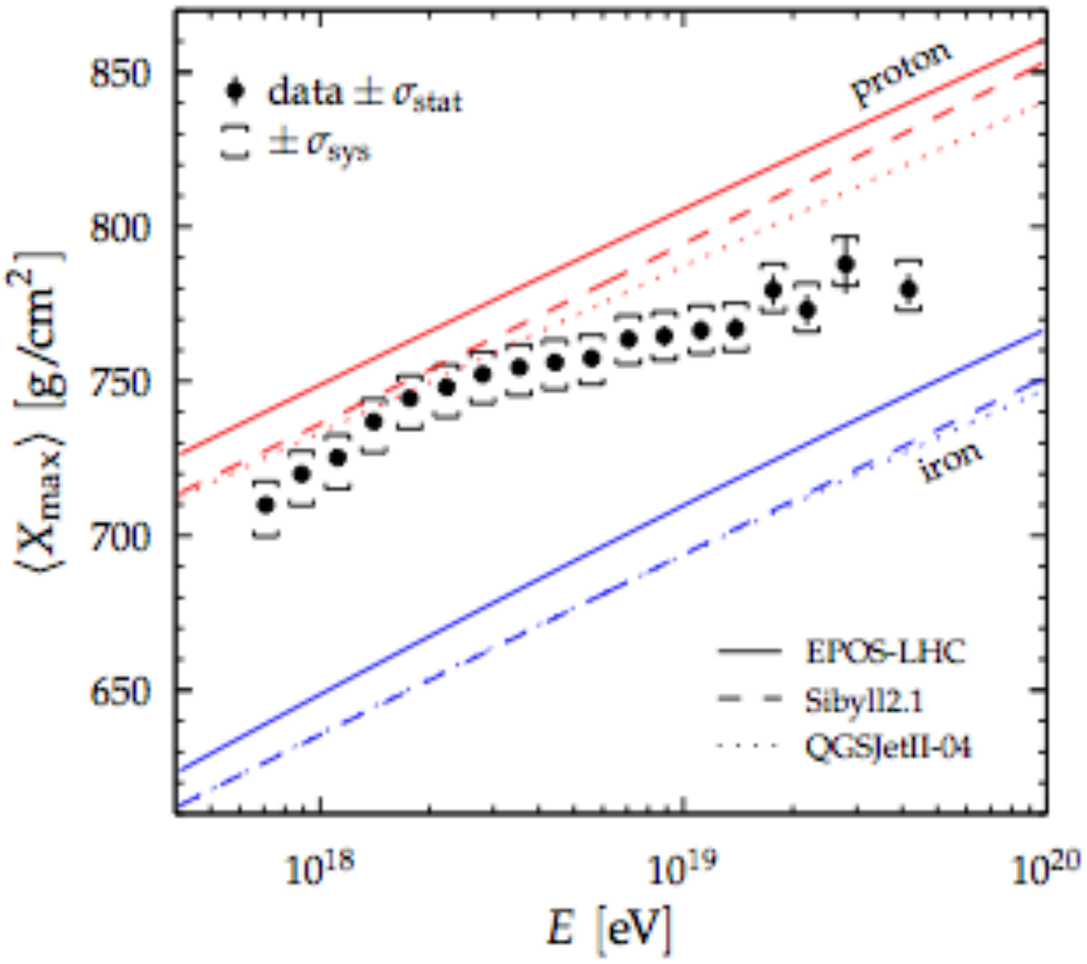


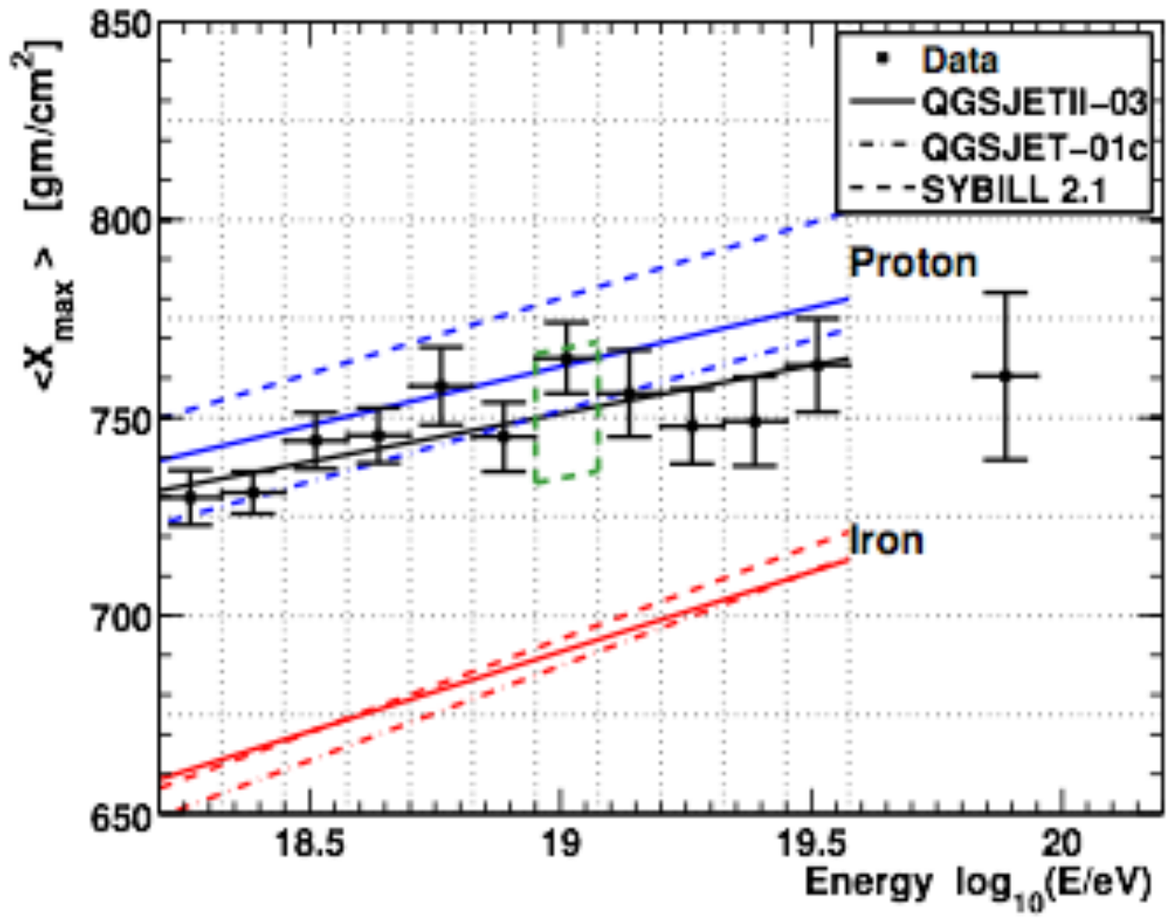
The Pierre Auger Collaboration, Physical Review D 90, 122005 (2014)

Fitted fraction an quality for a scenario with a mixture of proton, helium, nitrogen and iron nuclei. The upper panels show the species fractions and the lower panel shows the p-values.

Comparison Auger TA

M. Unger, ICRC 215 proceedings

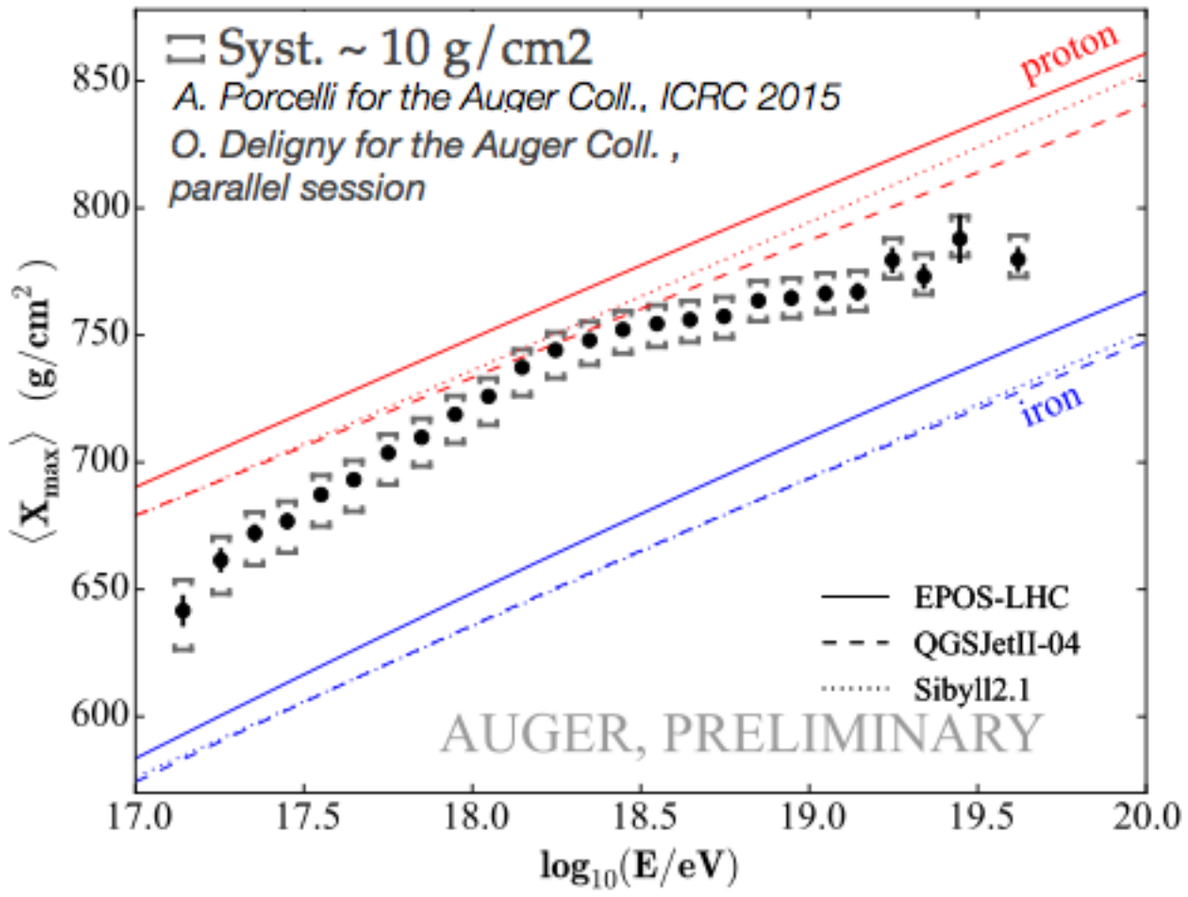




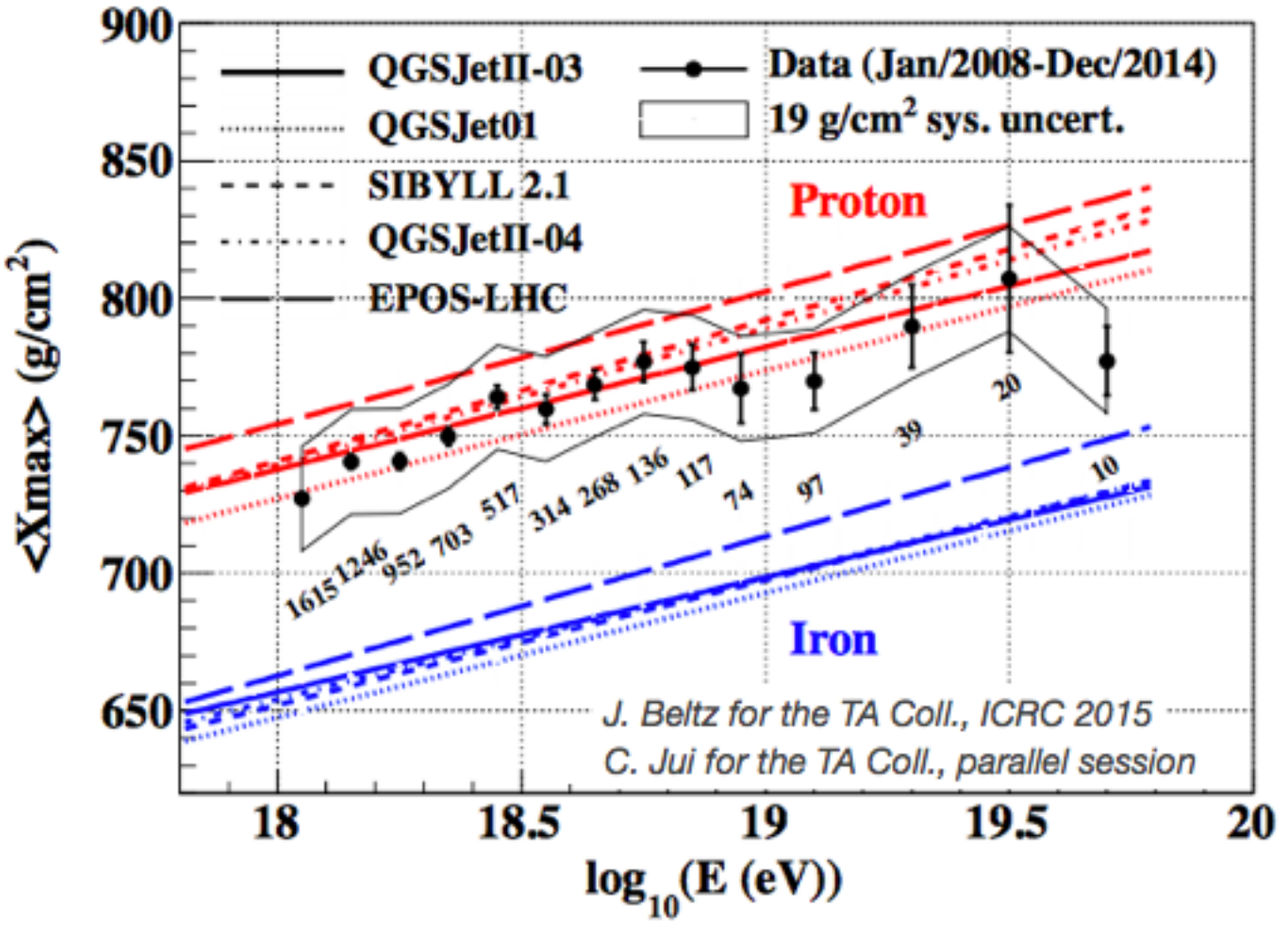
〈Xmax〉 as measured by the Pierre Auger (left) and Telescope Array (right) Collaborations [2, 3]. The colored lines denote predictions of air-shower simulations (note that different models are shown in the left and right panel, only SIBYLL2.1 is the same). The black line on the right panel is a straight-line fit to the TA data. Systematic uncertainties are indicated by brackets (left) and by the green dashed box (right).

Mass composition from Xmax

Pierre Auger Observatory



Telescope Array

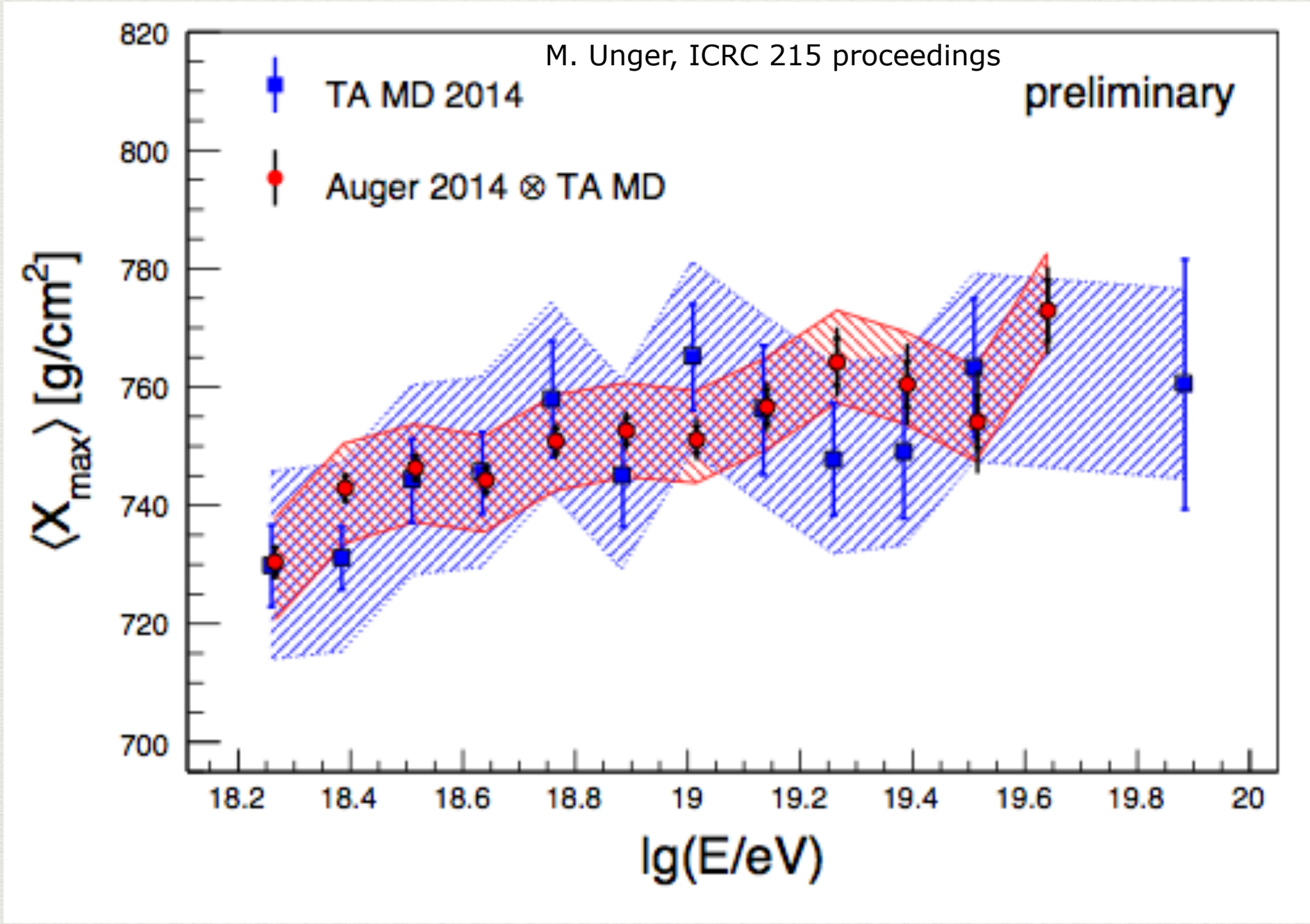


Change in composition and break point at E ~$10^{18.3}$ eV

Proton dominant composition

Similar conclusions from $\langle X_{max} \rangle$ and $\sigma(X_{max})$
Flux suppression region not covered by FD measurements

Comparison Auger TA



Comparison of ⟨Xmax⟩ as measured with the MD of TA (blue squares) and the ⟨Xmax⟩ of the Auger data folded with the MD acceptance (red circles). The data points are slightly shifted horizontally for better visibility. In the case of the Auger points, the inner error bars denote the statistical uncertainty of the measurement and the total error bar also includes contributions from the limited statistics of simulated events used for the folding. The colored bands show the systematic uncertainties of the Xmax scales of each experiment

Conclusions

- Clear feature in the spectrum (Ankle + Cut-off)
- Very weak anisotropies on large scale (Mag. Field ?), no point sources, no photons, no neutrons, no bright stars… North/south sky difference ?
- Composition is hadronic, very likely mixed but no or very little iron

WHAT AND WHERE ARE THE SOURCES ?