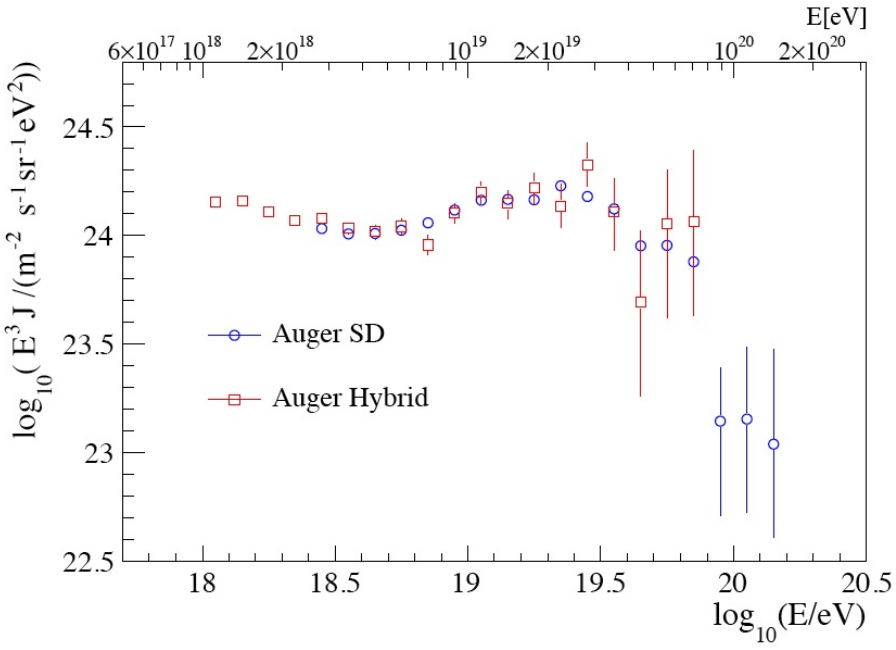
UHECR spectrum

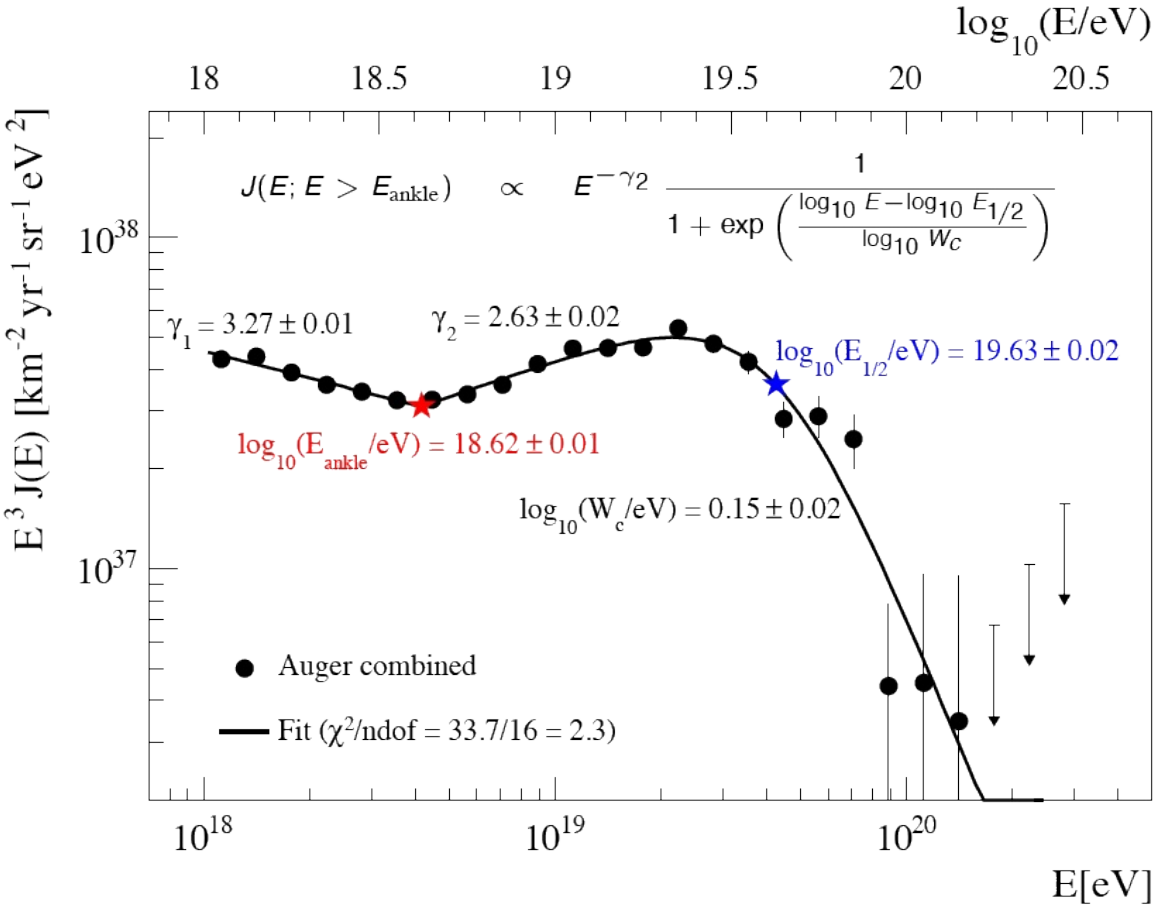
F.Salamida for the Pierre Auger Collaboration, ICRC 2011



- **SD Data** (Jan'04 - Dec'10, 20905km^2 sr yr)
  - Core contained
  - Zenith angle < 60°
  - E > $10^{18.4}$eV (fully efficient)
- **Hybrid Data** (Nov'05 - Sep'10)
  - Core contained
  - Zenith angle < 60°
  - E > 10^{18}eV (fully efficient)
- **Combined**
  - 22% systematic uncertainty on the energy scale

Suppression of the CR flux

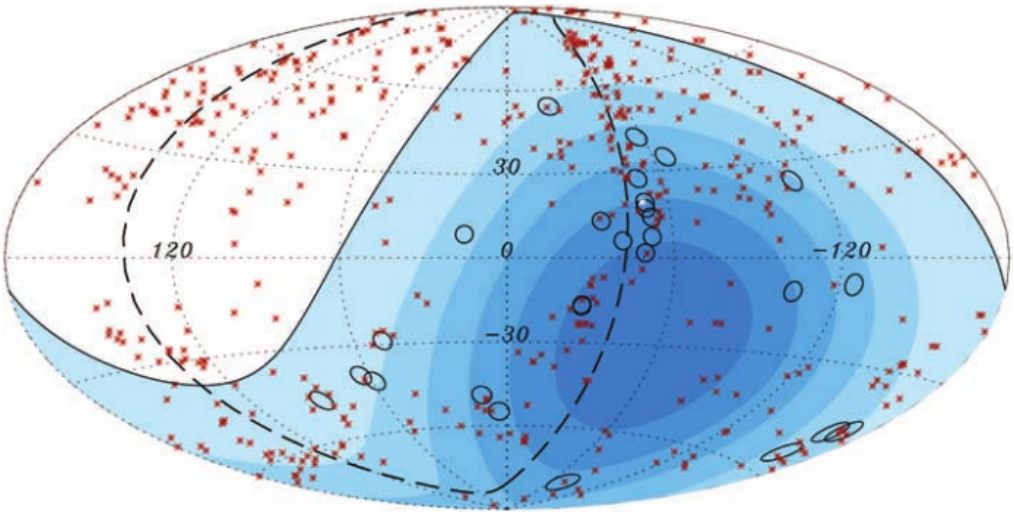
F.Salamida for the Pierre Auger Collaboration, ICRC 2011



GZK cut-off?

Anisotropy (Science, 2007)

Pierre Auger Collaboration, Science 318 (2007) 938



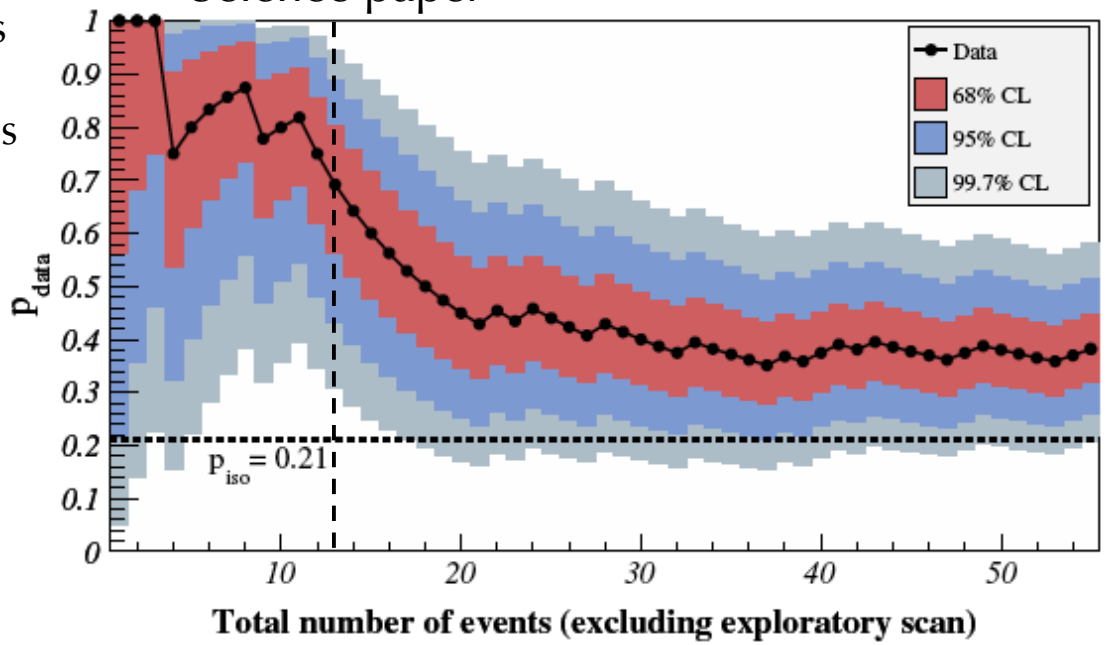
- Correlation with AGN with redshift < 0.018 (75Mpc)
- Auger data: E>56 EeV (5.6×10^{19}eV)
- 20 out of 27 events correlate within 3.1°
- Anisotropy at >99% CL

Anisotropy (as of 2010)

Pierre Auger Collaboration, Astropart. Phys. 34 (2010) 314

Science paper

Fraction of events correlating with nearby VCV AGNs

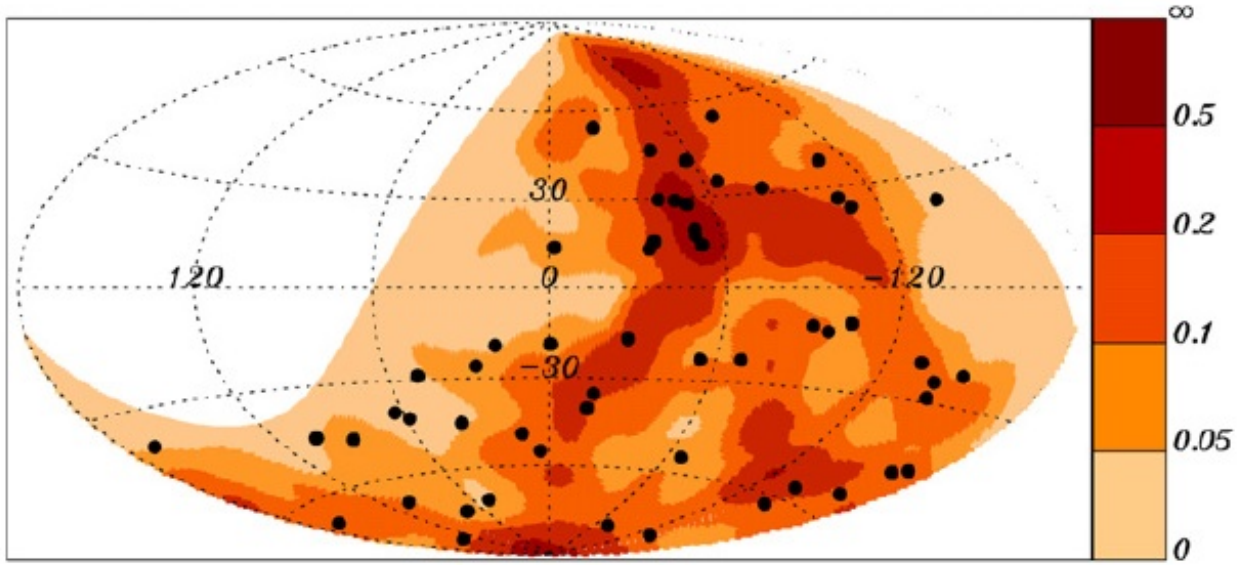


38%

Period	Dates	Exposure (km^2 sr y)	N	k	k_{iso}
I	1 January 2004–26 May 2006	4390	14	8	2.9
II	27 May 2006–31 August 2007	4500	13	9	2.7
III	1 September 2007–31 December 2009	11,480	42	12	8.8
Total	1 January 2004–31 December 2009	20,370	69	29	14.5
II + III	27 May 2006–31 December 2009	15,980	55	21	11.6

Correlation with Matter distribution

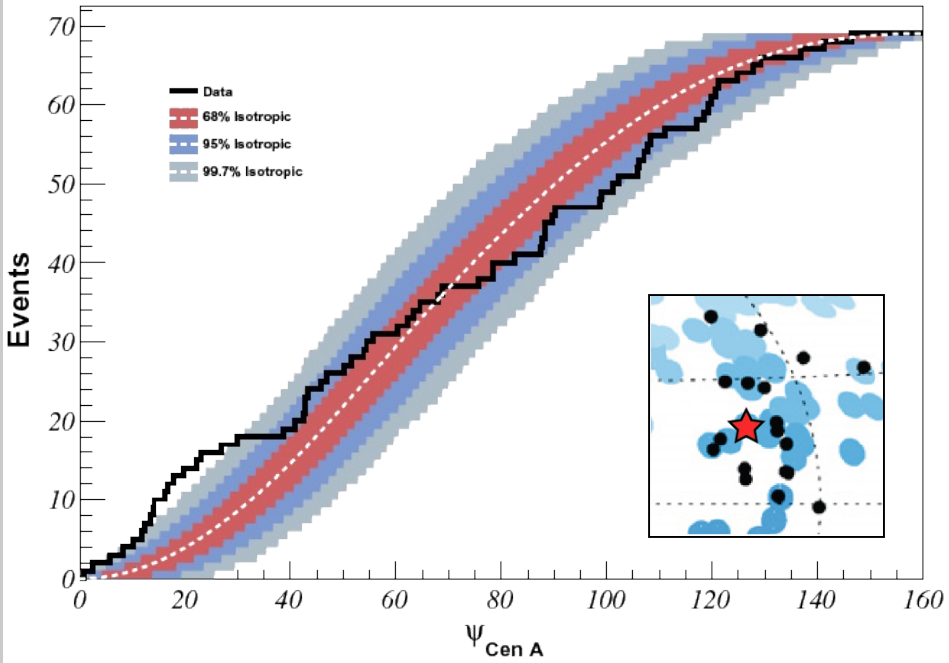
Pierre Auger Collaboration, Astropart. Phys. 34 (2010) 314



Black dots: The 69 Auger events with E>55EeV
2MRS catalog: density map with a 5° smoothing.

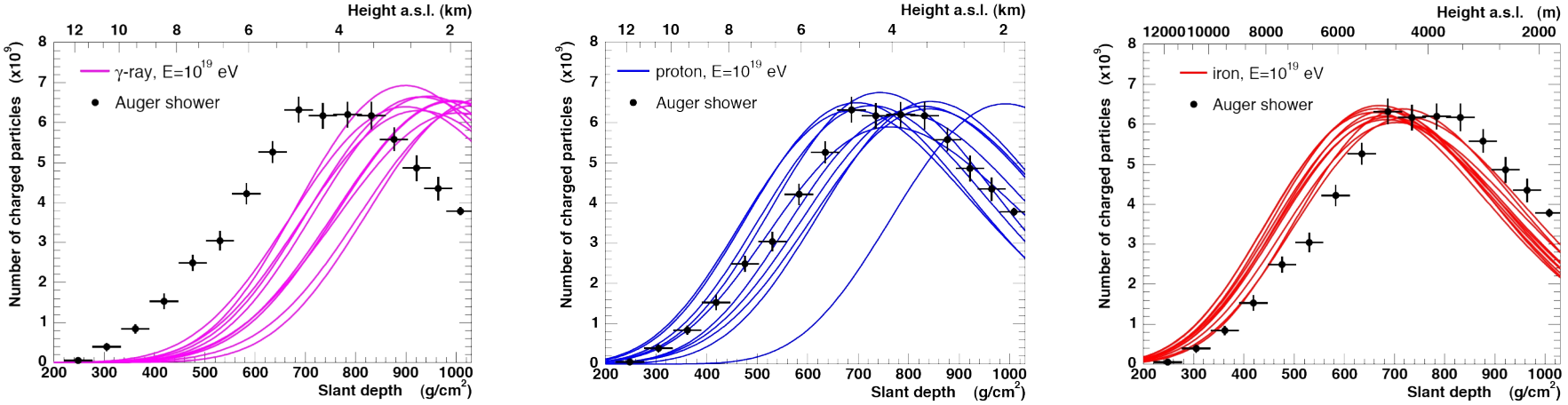
Centaurus-A

Pierre Auger Collaboration, Astropart. Phys. 34 (2010) 314



- Cen-A, closest AGN from us (~4Mpc)
- Maximum excess within separation angle of 18°
  - 13 out of 69 events, 3.2 expected for isotropic flux
- Excess found *a posteriori*. Need independent data to establish its statistical significance.
- No evidence for anisotropy at lower energies around Cen-A at any angular scales
  - Pierre Auger Collaboration, JCAP06 (2011) 022)

Composition study with FD



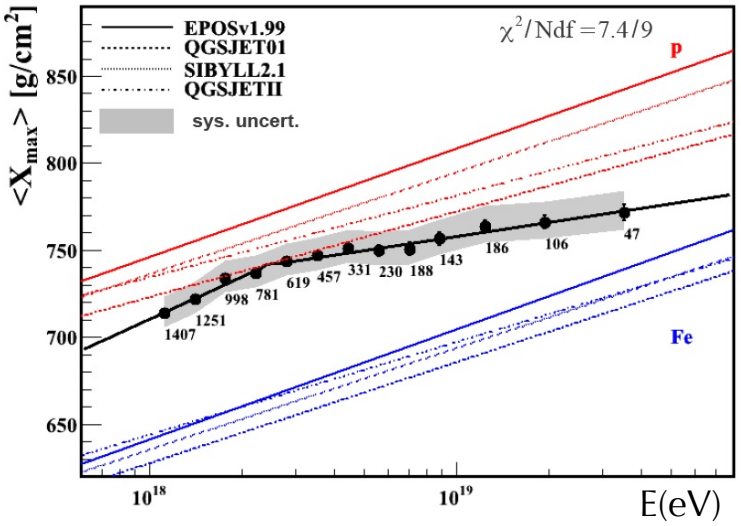
From: M.Unger, Snowpac and Snowcluster 2010

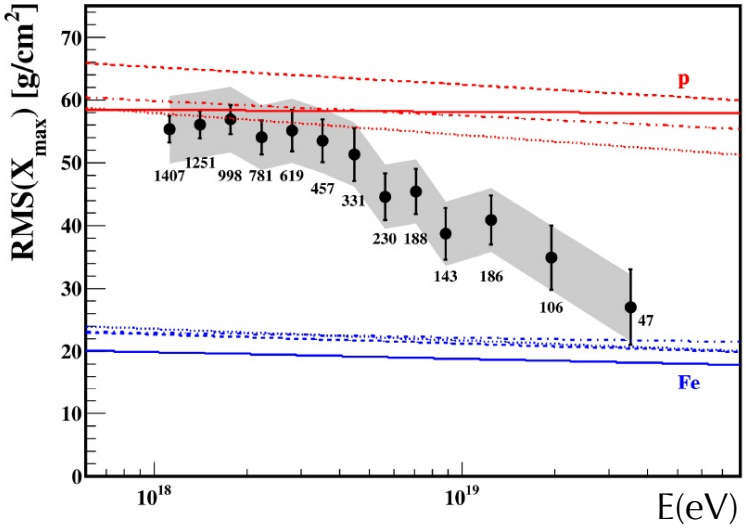
- Specific data selection to minimize biases (X_{max} in the field of view, …)
- 6744 hybrid events (Dec'04-Sep'09) with $E>10^{18}$eV

- X_{max} reflects mainly the properties of the first interaction
- The first interaction for heavier particle happens at shallower depth with less fluctuation
- The interpretation relies on hadronic models
  - Opportunity to study particle physics

Hadronic composition

P.Facal-Luis for the Pierre Auger Collaboration, ICRC 2011

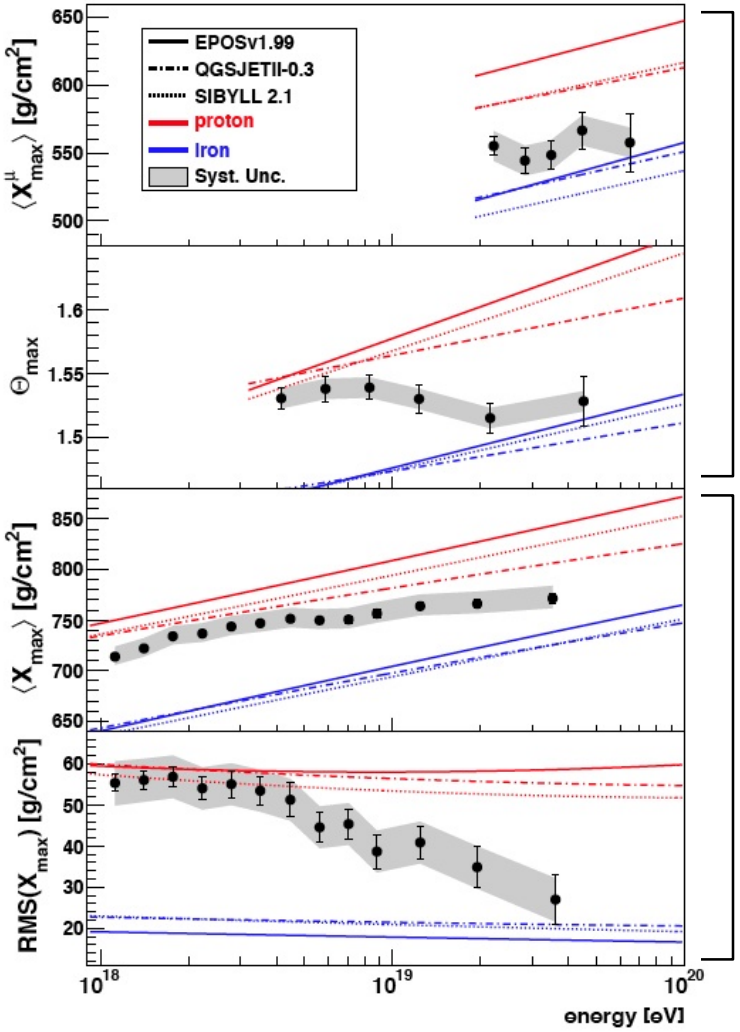




- Apparent transition towards heavier composition
- Break in $\langle X_{max} \rangle$ behavior seems to occur around the Ankle energy
- Break in RMS(X_{max}) at roughly the same energy

Composition study

D.Garcia-Pinto for the Pierre Auger Collaboration, ICRC 2011

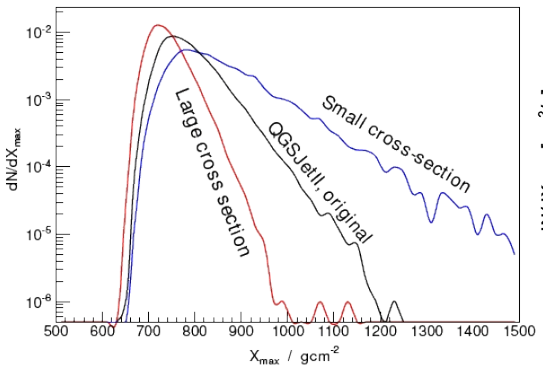


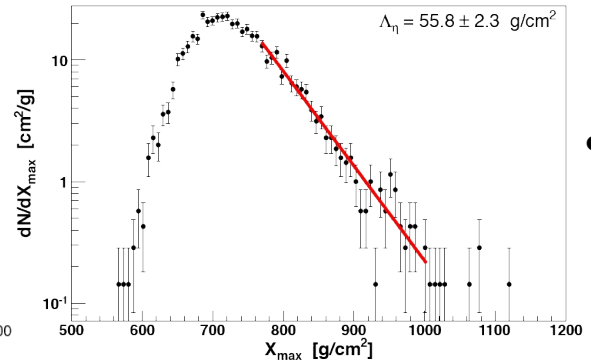
SD

FD

Hadronic interaction

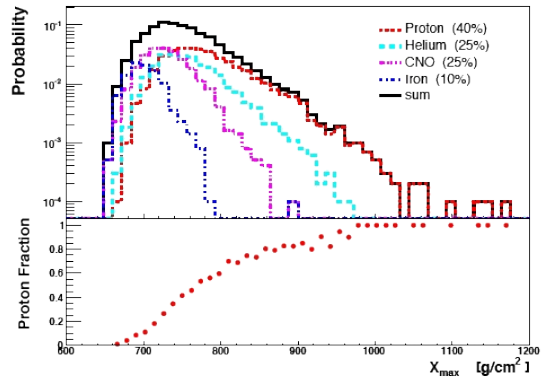
R.Ulrich for the Pierre Auger Collaboration, ICRC 2011

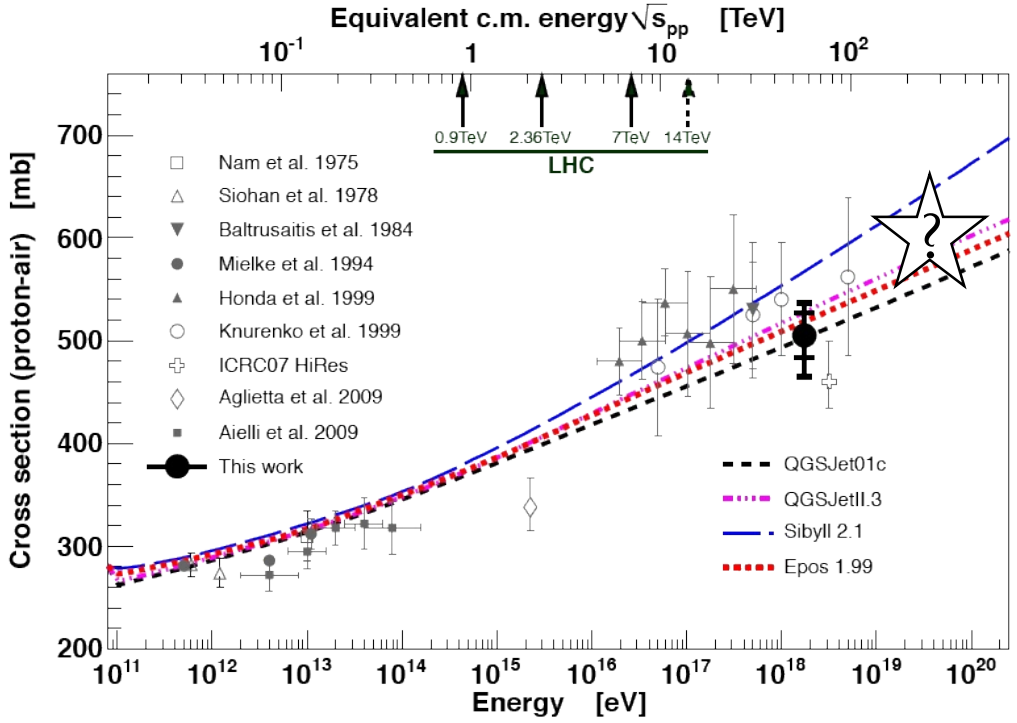




- Energy interval: 10^{18}-$10^{18.5}$eV

$$\sigma_{p-air} = \left(505 \pm 22_{stat} \left(^{+26}_{-34}\right)_{sys}\right) mb$$

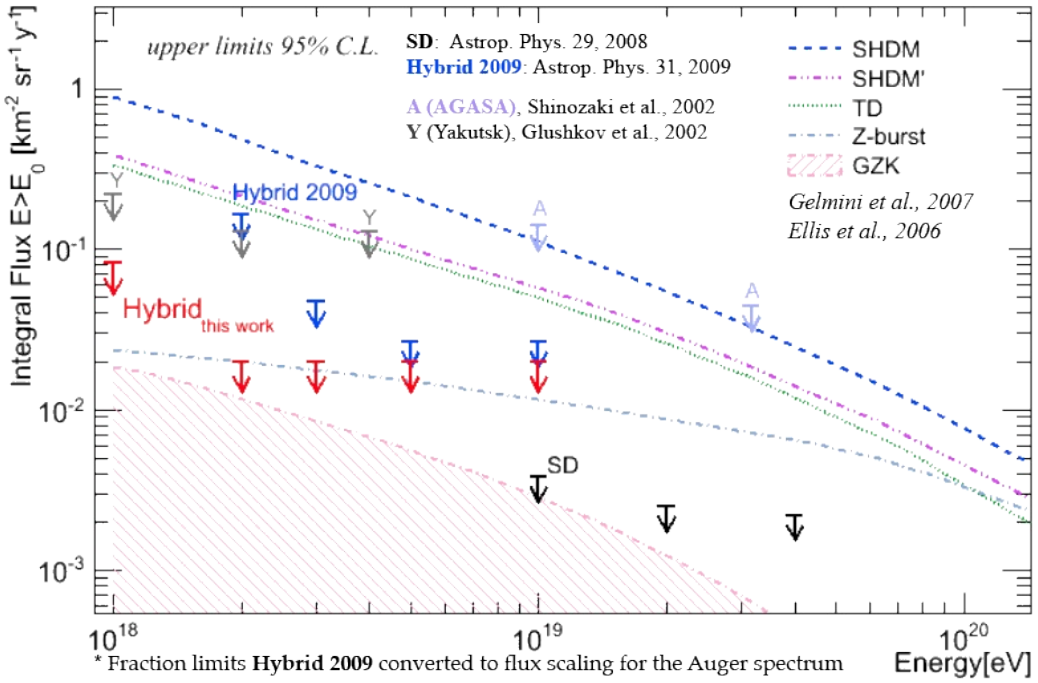




- High p-A cross section can mimic $\langle X_{max} \rangle$ and RMS(X_{max}) results
- Tail of X_{max}-distribution fit
  - $dN/dX_{max} \propto \exp(-X_{max}/\Lambda_\eta)$

Photon limits

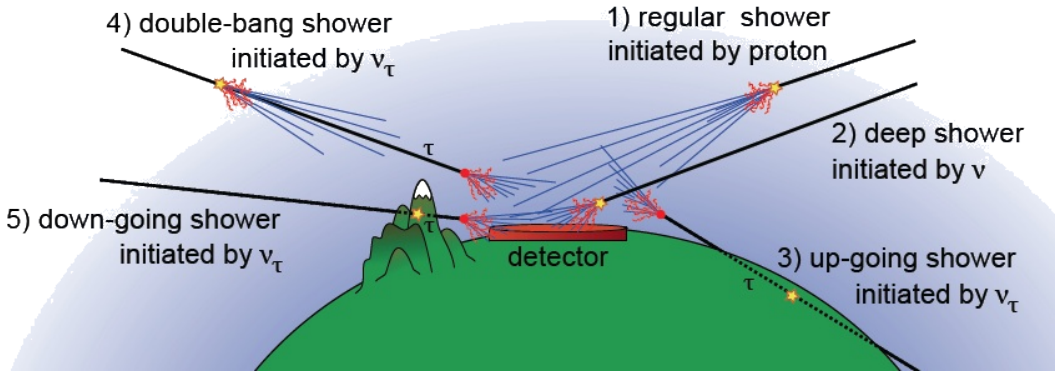
Photon limits: M.Settimo for the Pierre Auger Collaboration, ICRC 2011



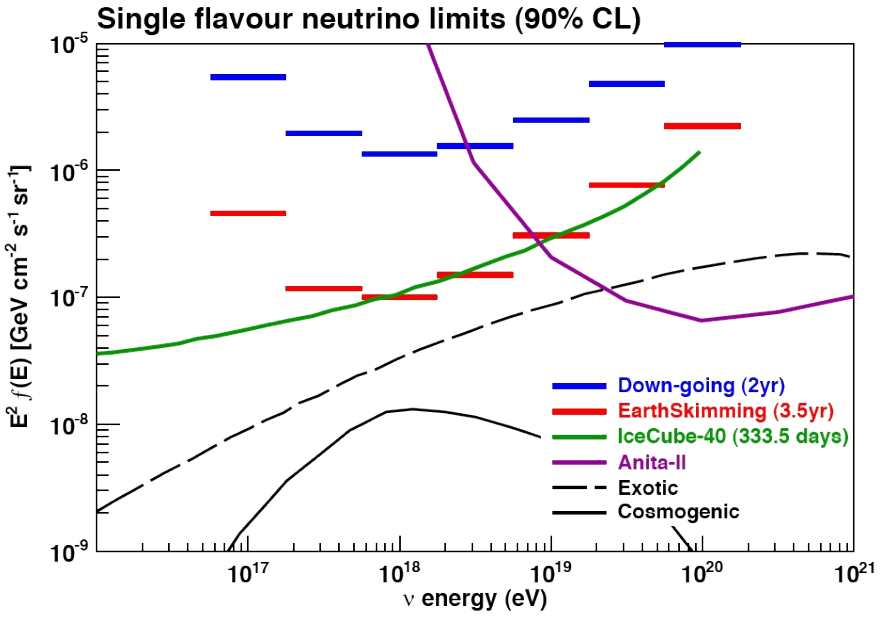
- Upper limits - integrated photon fraction:
  - 0.4%, 0.5%, 1.0%, 2.6%, 8.9% @ E>1, 2, 3, 5, 10 EeV
- Strongly constrain Top-Down models
- GZK region within reach in the next few years

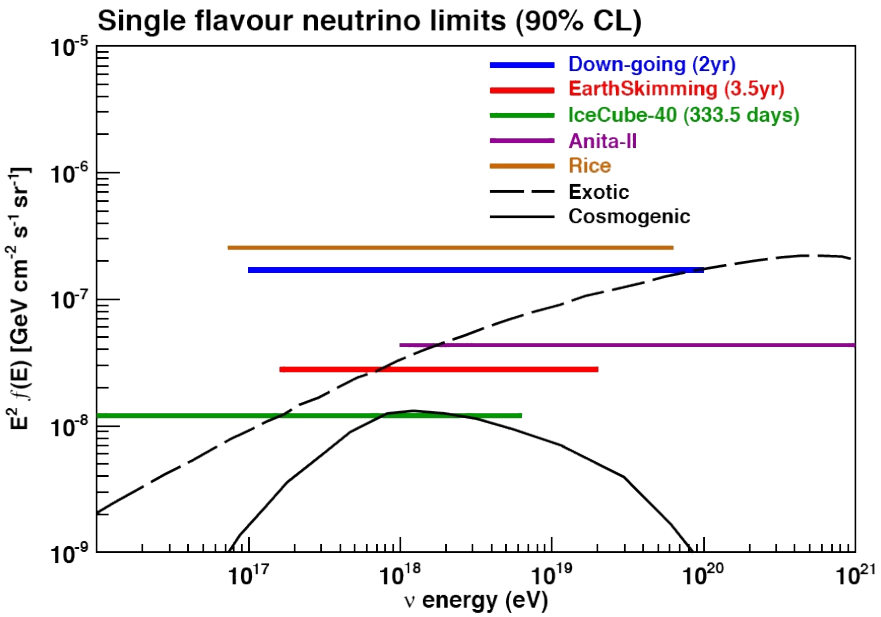
Neutrino limits

Neutrino limits: Y.Guardincerri for the Pierre Auger Collaboration, ICRC 2011



- Analysis of very inclined (down-going) showers and up-going showers
- Young (= deep) showers





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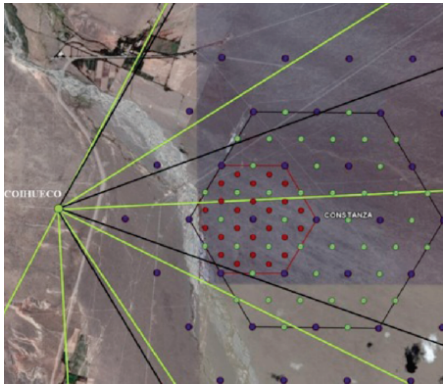
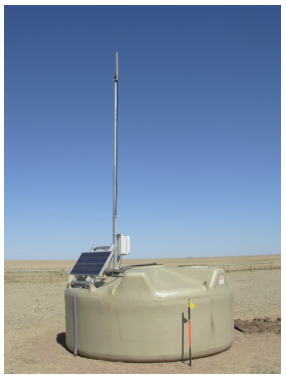
Enhancements, R&D and the Future

- Observatory enhancements at lower energy:
  - In-fill array
  - HEAT
  - AMIGA



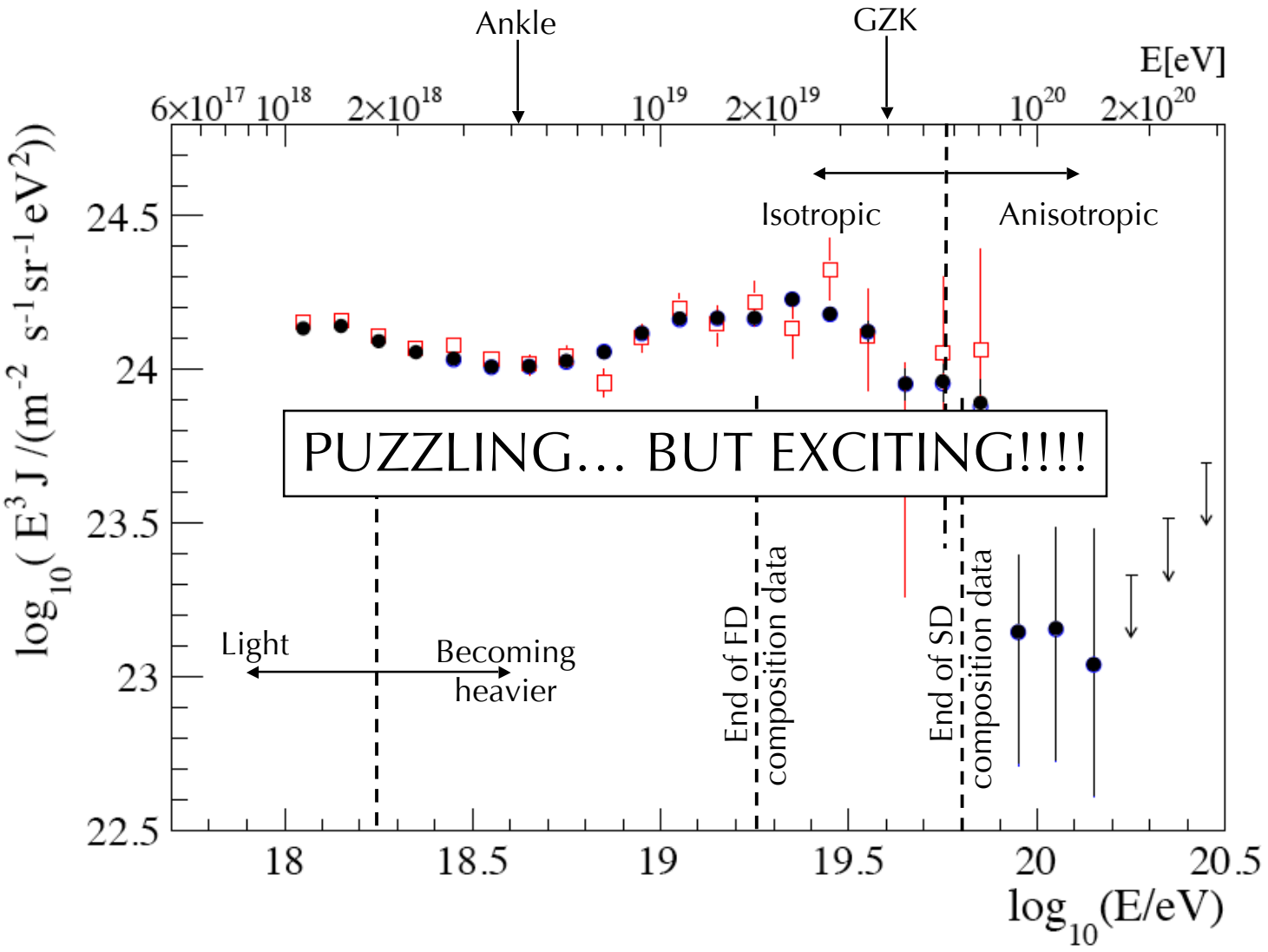
- R&D:
  - Radio (AERA, EASIER)
  - Microwave (MIDAS, AMBER, EASIER)
  - R&D array in southeast Colorado



AMBER

- The Future of UHECR studies:
  - A larger ground array in the northern hemisphere?
  - (Space: JEM-EUSO, …)

Summary



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References

Collection of ICRC 2011 contributions for the Pierre Auger Observatory

arXiv:1107.4809 [astro-ph]: The Cosmic Ray Energy Spectrum and Related Measurements

arXiv:1107.4804 [astro-ph]: Studies of Cosmic Ray Composition and Hadronic Interaction models

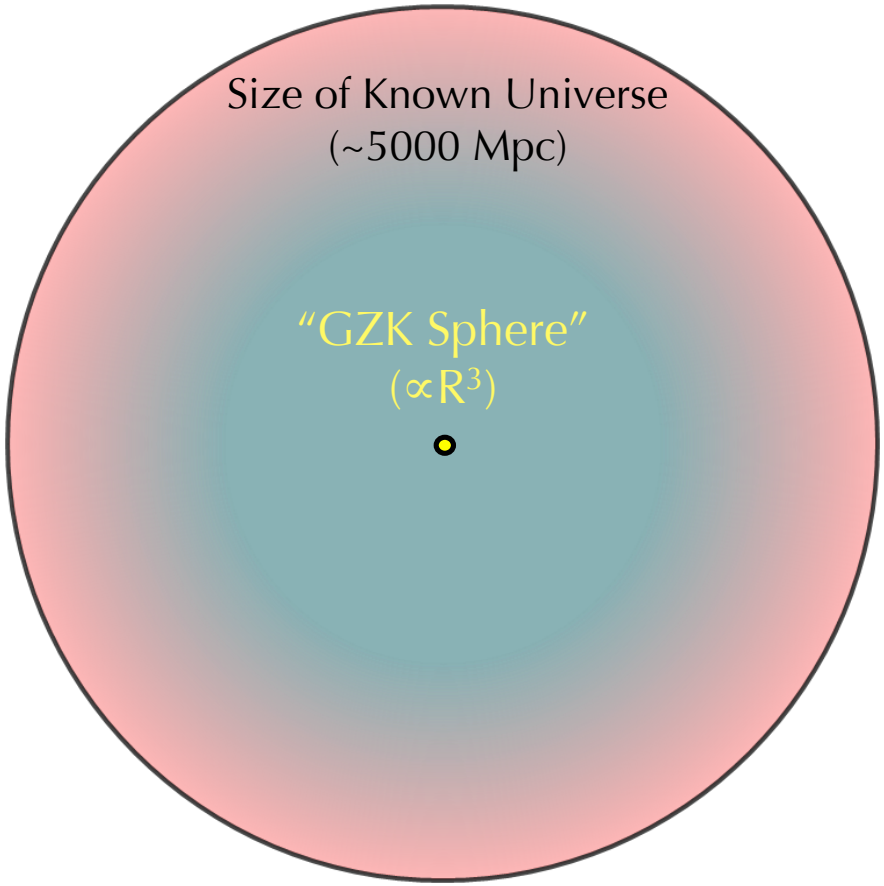
arXiv:1107.4805 [astro-ph]: Other Astrophysical Observations

arXiv:1107.4806 [astro-ph]: Operation and Monitoring

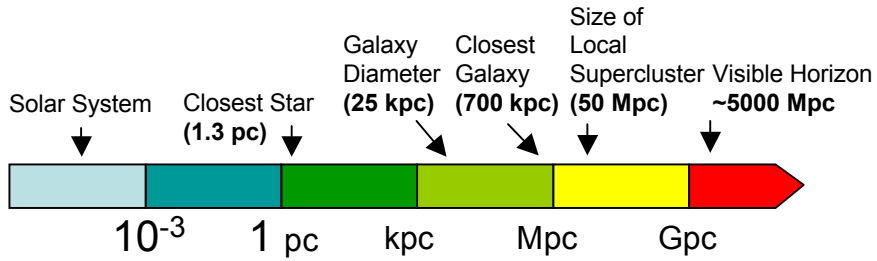
arXiv:1107.4807 [astro-ph: Enhancements

Backup slides

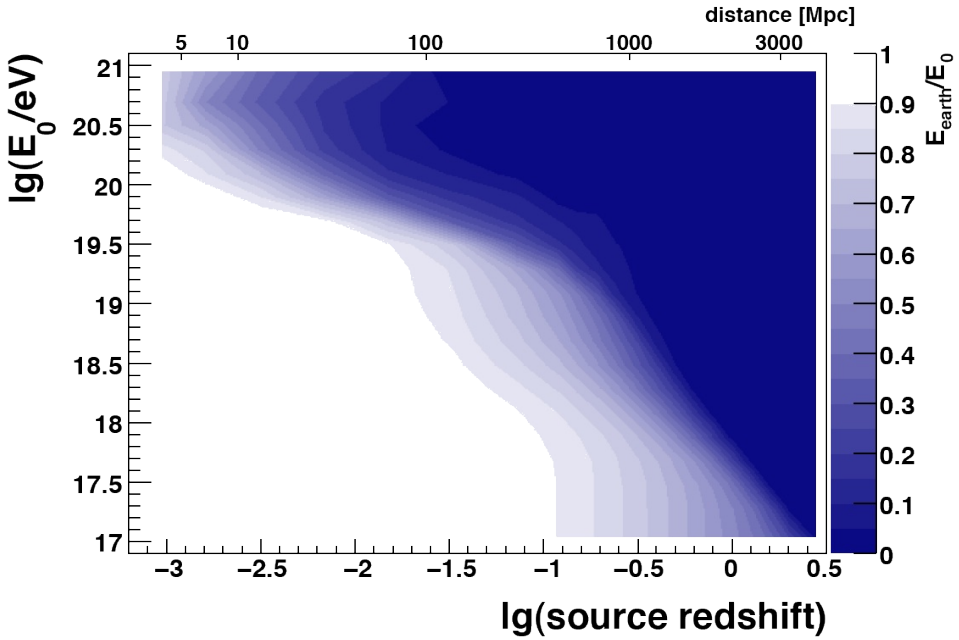
The GZK horizon / sphere



The sources are nearby!



1 parsec (pc) = 3.26 light-years ~3x10^{13} km



M.Unger, 21st European Cosmic Ray Symposium, 2008, Kosice, arXiv:0812.2763

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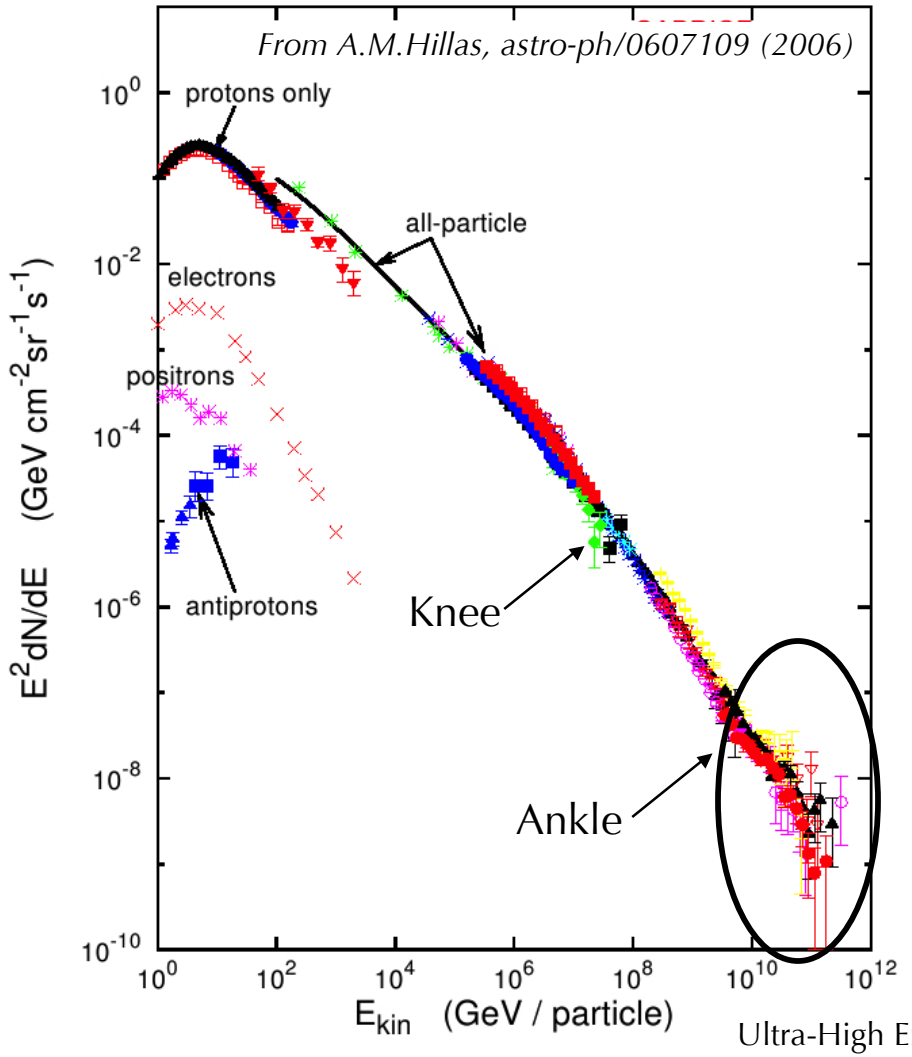
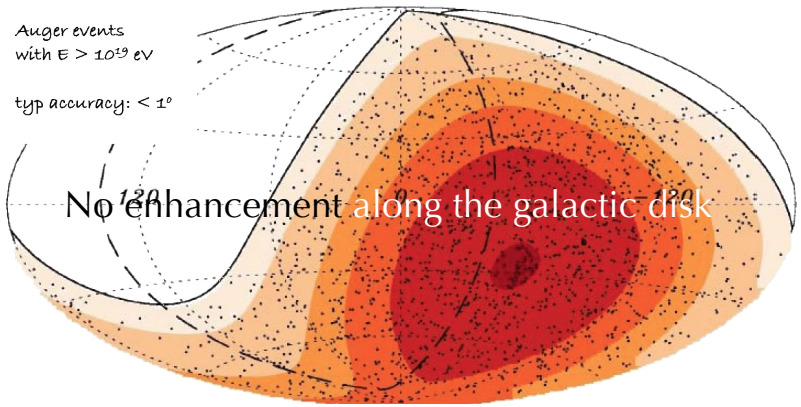
The cosmic-ray energy spectrum



- Power-law flux over many orders of magnitude
- Direct measurements only below 10^{15}eV (10^6GeV)
- Features: knee, (2nd knee), ankle
- End of the spectrum?
  - Flux at 10^{20}eV (10^{11}GeV): 1particle/km^2/century



J.Knapp, symposium on current topics in astroparticle physics, Chicago (2010)

Ultra-High Energy Cosmic-Rays (UHECRs) - E>10^{18}eV

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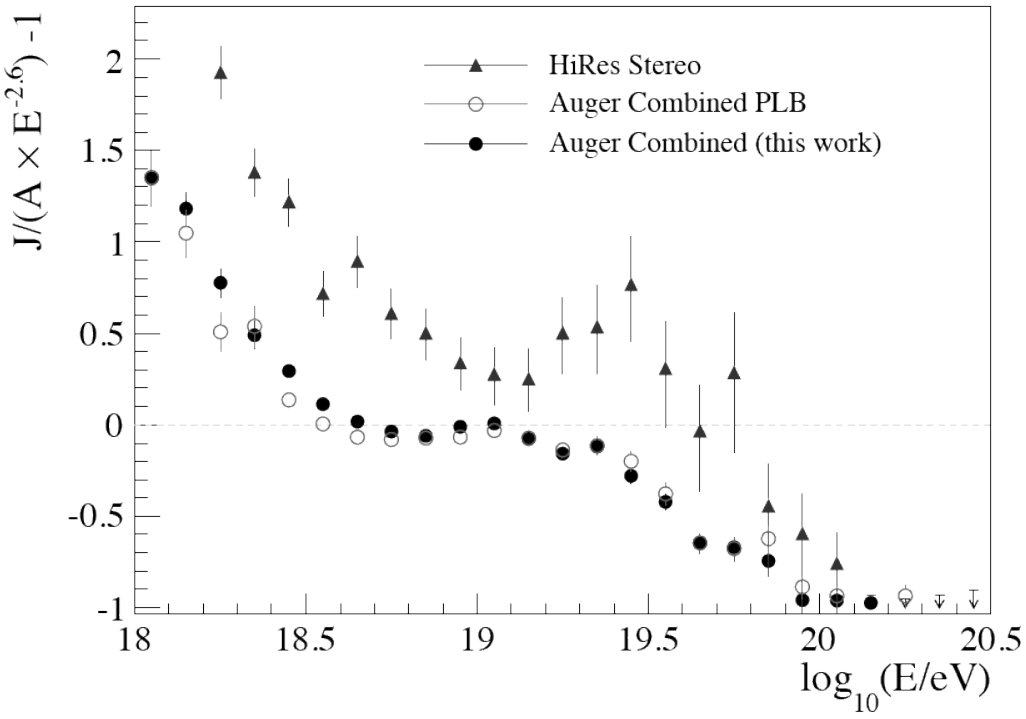
UHECR spectrum energy scale

F.Salamida for the Pierre Auger Collaboration, ICRC 2011

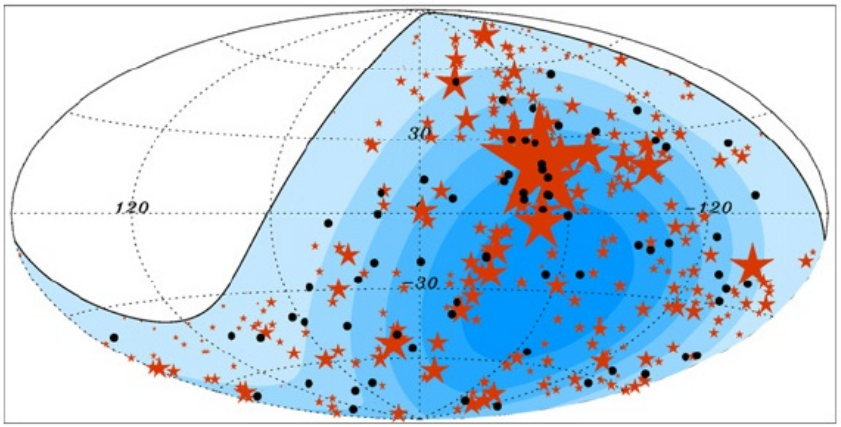


Direction of energy scale shift

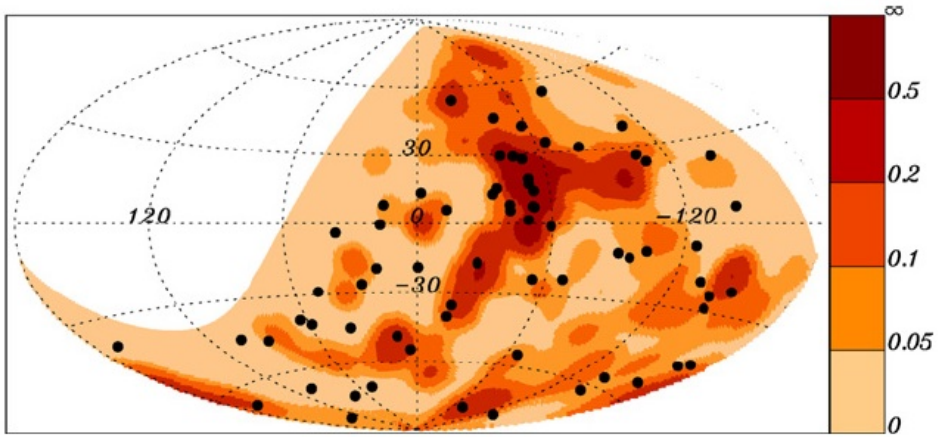
- **Auger / HiRes**
  - 22 / 17 % uncertainty on the energy scale

Correlation with Matter distribution

Pierre Auger Collaboration, Astropart. Phys. 34 (2010) 314



Black dots: Auger events E>55EeV
Red star: AGNs of the 58-month Swift-BAT catalog.
Star area proportional to the assigned weight.



Density map with a 5° smoothing.