UHE Cosmic Rays and the Auger experiment

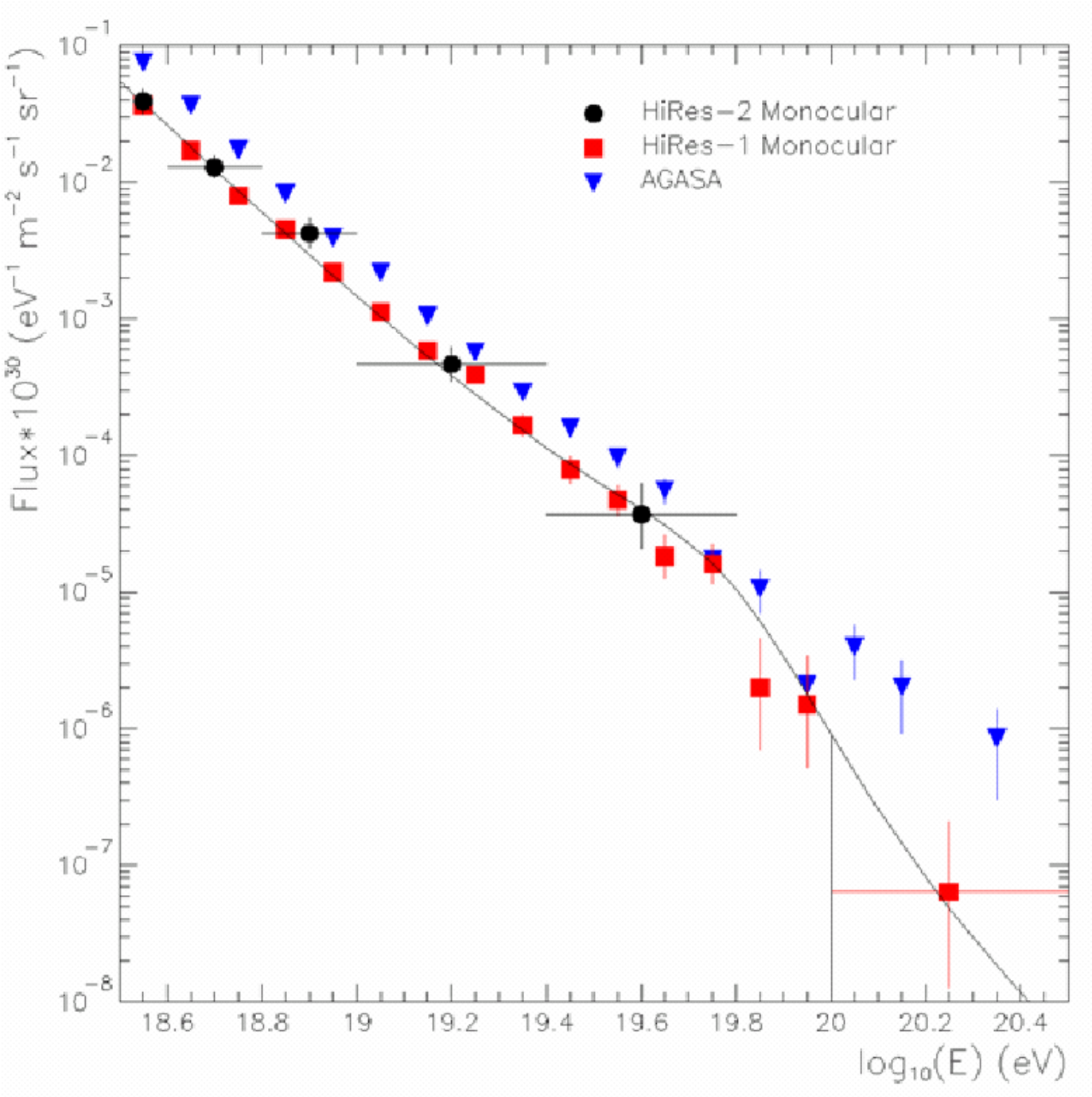
Sergio Petrera, GSSI and L'Aquila University

- Ten years of UHE Cosmic Rays
- The Pierre Auger Observatory
- L'Aquila/LNGS Auger group

UHE Cosmic Rays 2005

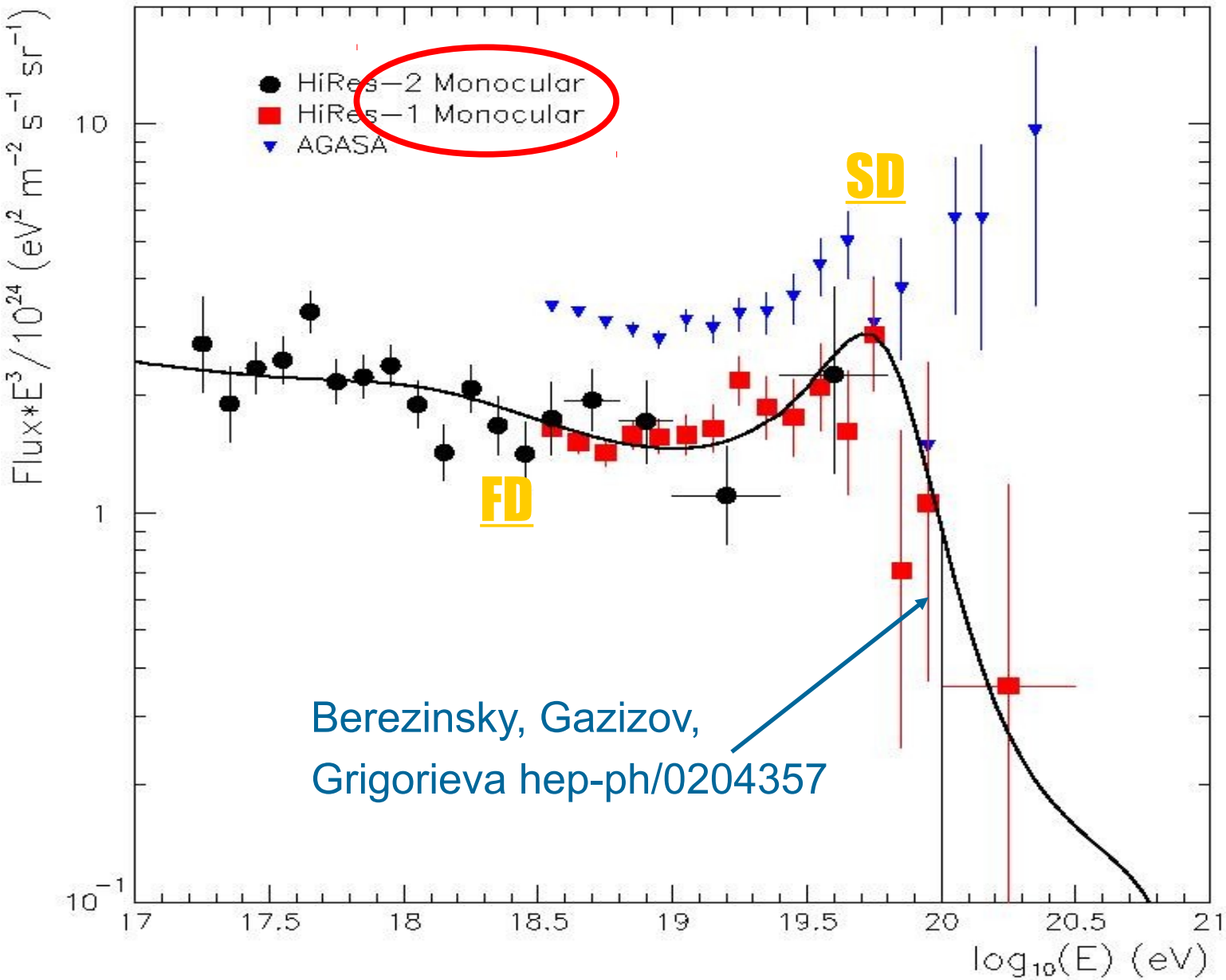
Is there a spectrum cutoff?
Predicted by Greisen and Zatsepin-Kuzmin 1966

AGASA / HiRes


HiRes−2 Monocular
HiRes−1 Monocular
AGASA
Flux*10^30 (eV^-1 m^-2 s^-1 sr^-1)
log10(E) (eV)
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
18.6
18.8
19
19.2
19.4
19.6
19.8
20
20.2
20.4

AGASA / HiRes

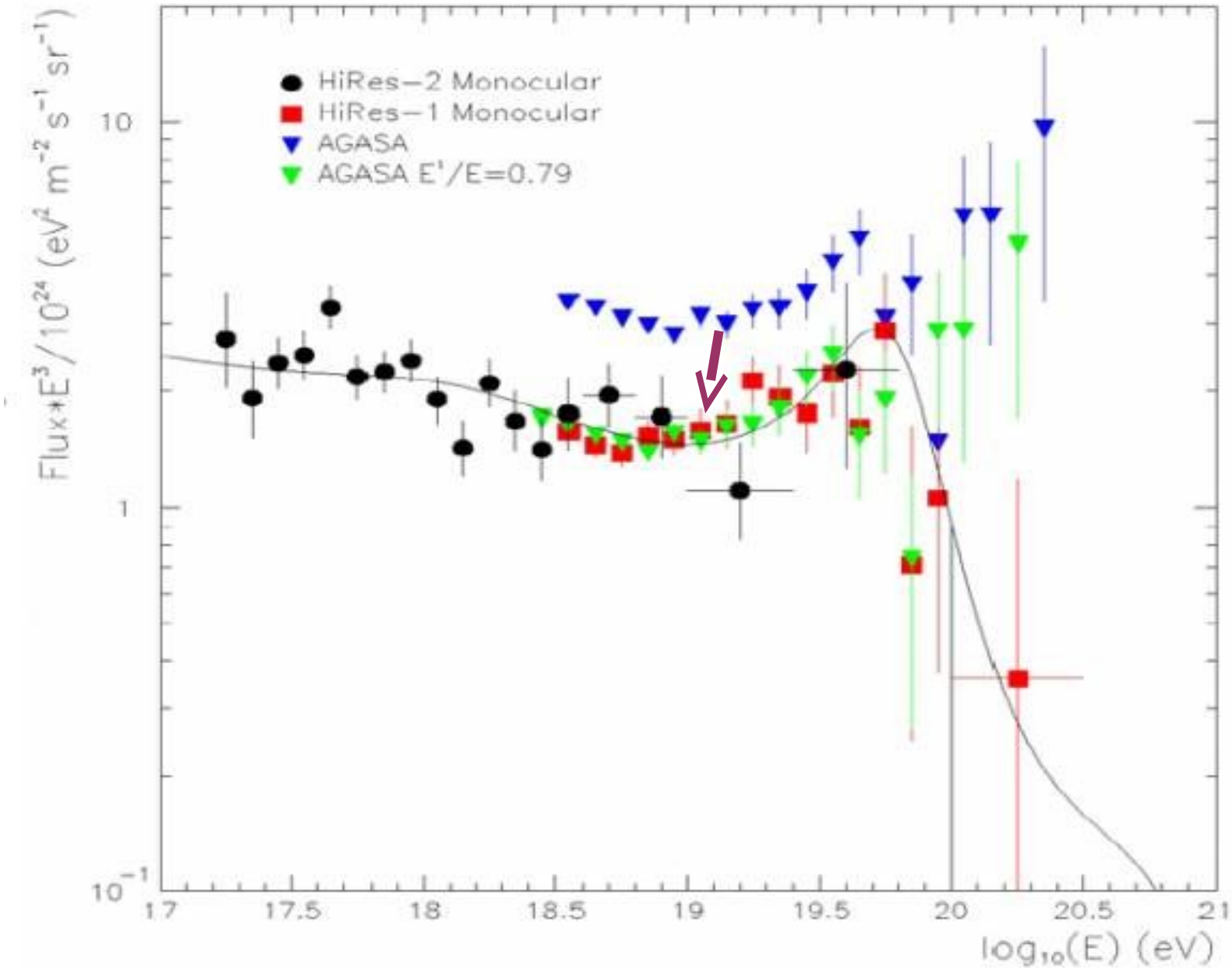
HIRES Coll. astro-ph/0208301



Berezinsky, Gazizov,
Grigorieva hep-ph/0204357

AGASA / HiRes

AGASA data renormalized by 20 % (Energy scale)



UHE Cosmic Rays 2005

Is there a spectrum cutoff?

Predicted by Greisen and Zatsepin-Kuzmin 1966

YES: CR interaction with photon background *(bottom-up scenario)*

NO: possible super-heavy relic particles *(top-down scenario)*

Implications on multi-messengers: γ, ν

UHE Cosmic Rays NOW

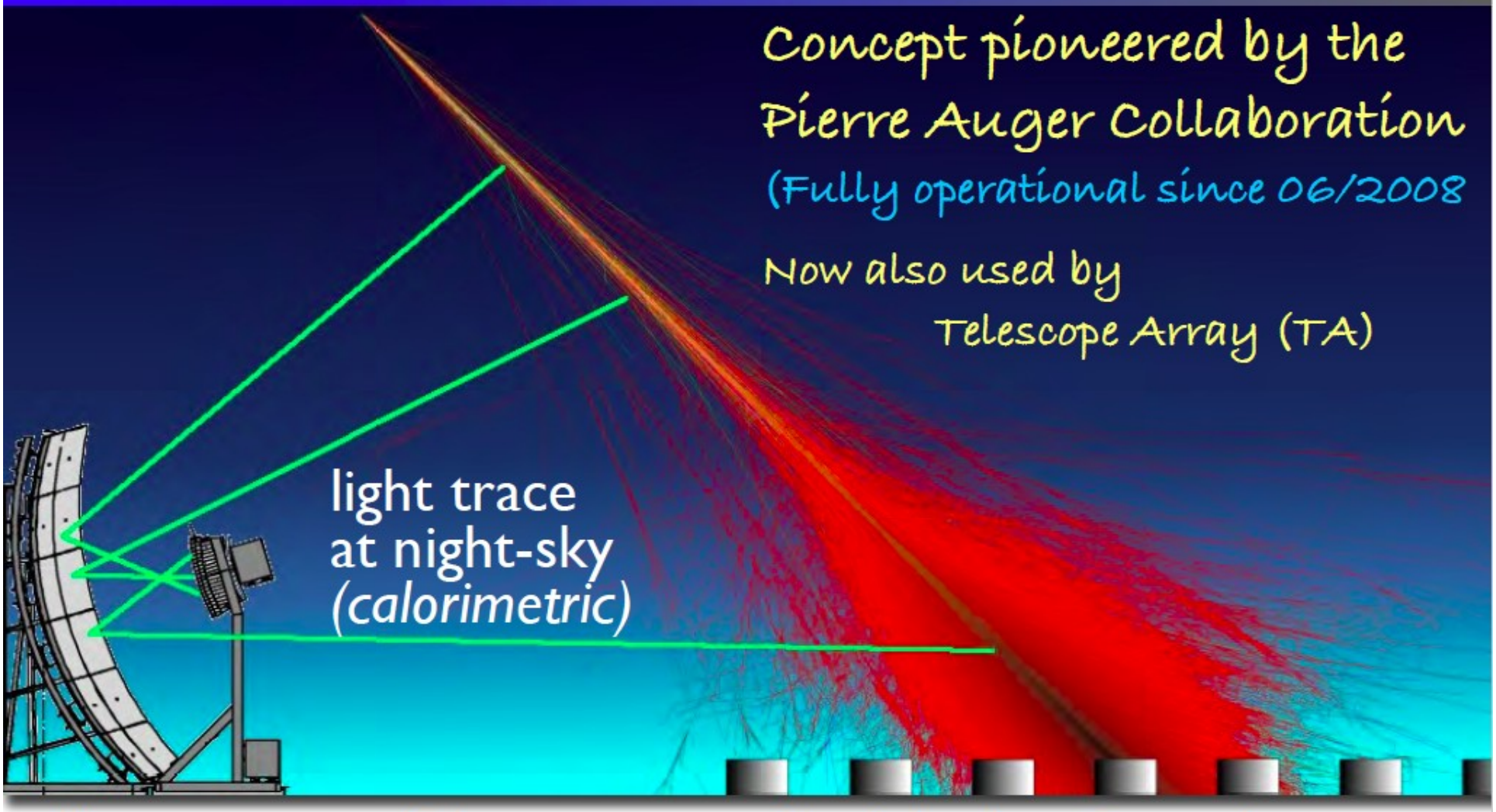
New experiments built

Exploiting both detection techniques
ground array sampling + fluorescence detection

Pierre Auger Observatory, Argentina
Start 2004, fully operational 2008

Telescope Array, Utah, U.S.
Operational 2008

Hybrid Observation of EAS

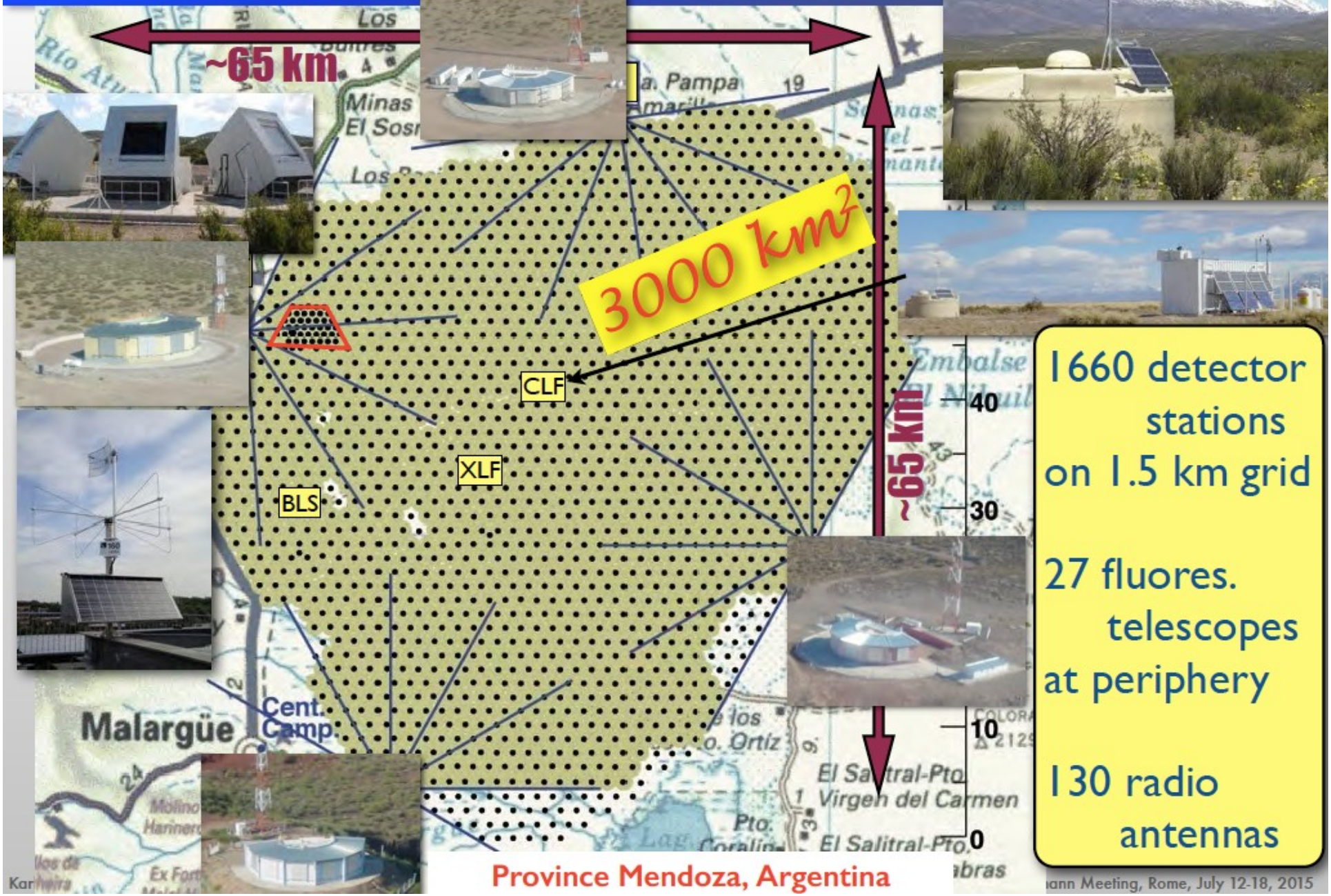


Fluorescence light

Particle-density and
-composition at ground

Also:
Detection of Radio- & Microwave-Signals

Pierre Auger Observatory



1660 detector stations on 1.5 km grid

27 fluores. telescopes at periphery

130 radio antennas

Auger Hybrid Observatory

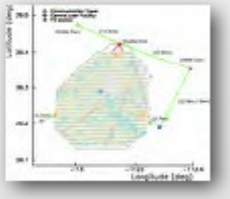
3000 km^2 area, Argentina

27 fluorescence telescopes plus

...1660 Water Cherenkov tanks

Auger and TA

Telescope Array (TA)
Delta, UT, USA
507 detector stations, 680 km^2
36 fluorescence telescopes

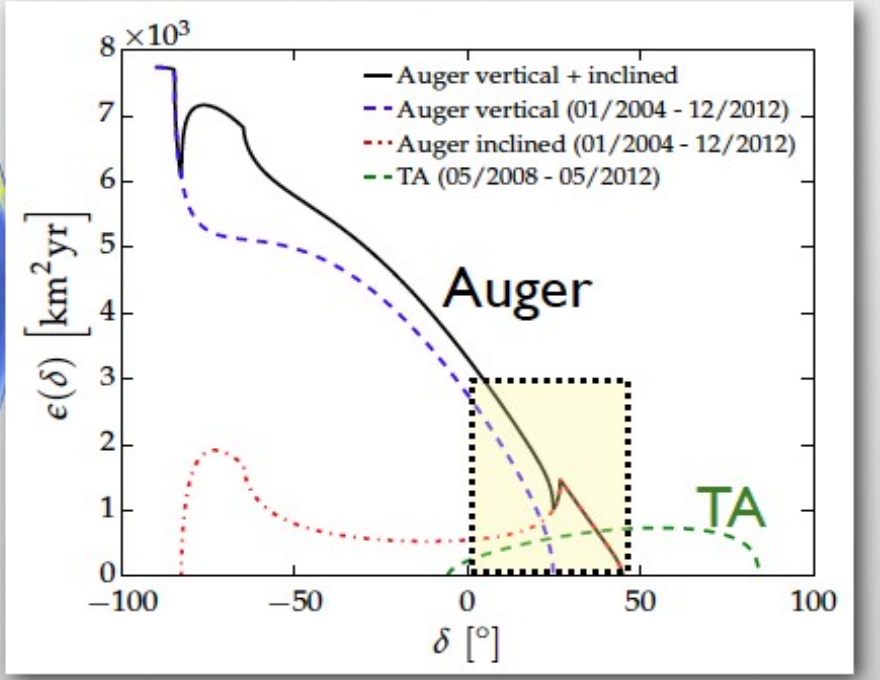


same scale

Pierre Auger Observatory
Province Mendoza, Argentina
1660 detector stations, 3000 km^2
27 fluorescence telescopes

Auger and TA can see the same sky

Auger: 01/2004 - 12/2012
TA: 05/2008 - 05/2012



Auger exposure ~8 times that of TA

Auger scientific results

- All-particle flux: *suppression above $10^{19.5}$ eV well established*
- Photon and neutrino limits: *top-down scenarios ruled out*
- Depth of shower maximum

  Xmax distributions vs energy, detector-unbiased moments, composition analysis in terms of elemental fractions
  Mass composition gets heavier
- Arrival direction distribution

  EeV dipole anisotropy, small angle correlation with sources (joint Auger-TA full sky search)
  UHECR sky surprisingly isotropic
- Air shower and hadronic interaction physics

  pp cross section, muon discrepancy (more muons than expected)

Possible data interpretations and astrophysical scenarios

Maximum-energy scenario, photo-disintegration scenario, proton-dominance model

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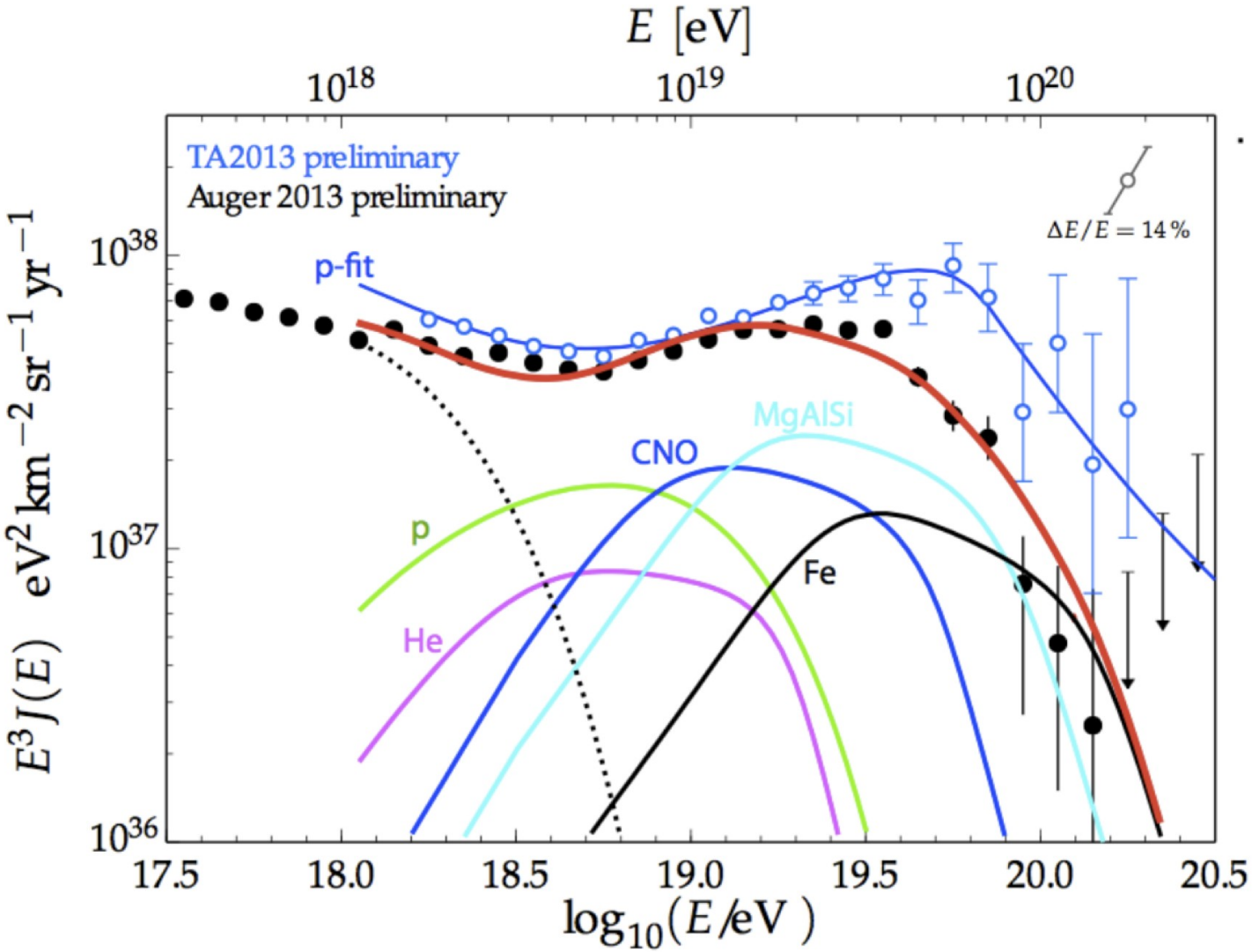
Astrophysical scenarios

V. Berezinsky et al. (2005), R. Aloisio, V. Berezinsky, and A. Gazizov, Astropart. Phys. 39-40 (2012) 129

R. Aloisio, V. Berezinsky, and P. Blasi, JCAP 1410 (2014) 10, 020

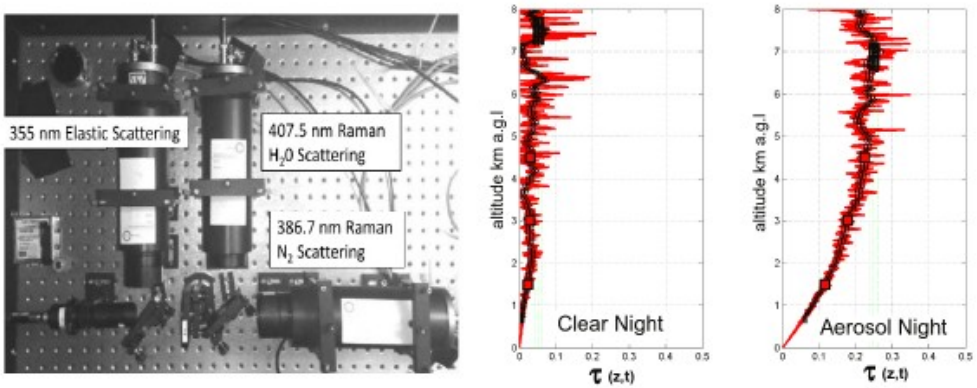


K-H. Kampert and P. Tinyakov, arXiv:1405.0575v1

L'Aquila / LNGS Auger group

Two main fields of interest:

- Atmospheric monitoring in the site
  Raman Lidar built in L'Aquila: benchmark of VAOD measurement



- Simulation Code from UHECR propagation *(SimProp)* developed in collaboration with R. Aloisio
  Astrophysical interpretation of spectrum and composition data

S. P.

Aurelio Grillo *Vincenzo Rizi* *DeniseBoncioli* *Armando di Matteo*

Thanks

Two new Auger papers on composition:

"*Depth of Maximum of Air-Shower Profiles at the Pierre Auger Observatory: Measurements at Energies above $10^{17.8}$ eV*"
PRD 90, 122005 (2014)

"Depth of Maximum of Air-Shower Profiles at the Pierre Auger Observatory: Composition Implications"
PRD 90, 122006 (2014)

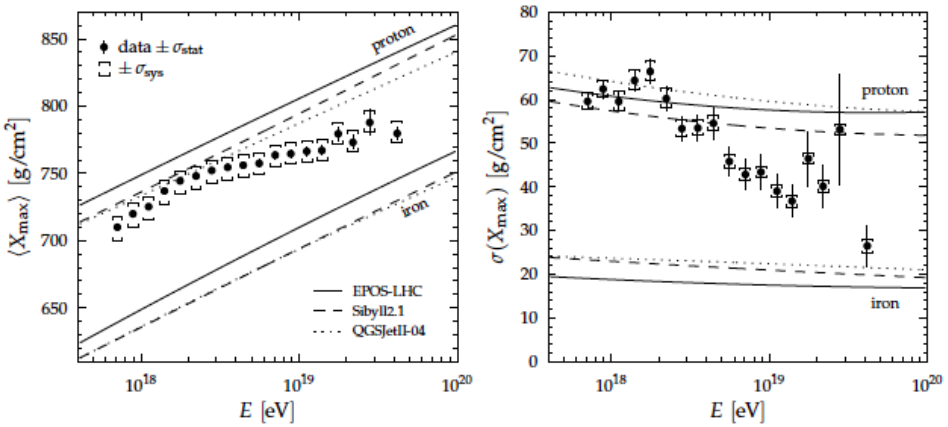


Figure 13: Energy evolution of the first two central moments of the X_{max} distribution compared to air-shower simulations for proton and iron primaries [80, 81, 95-98].

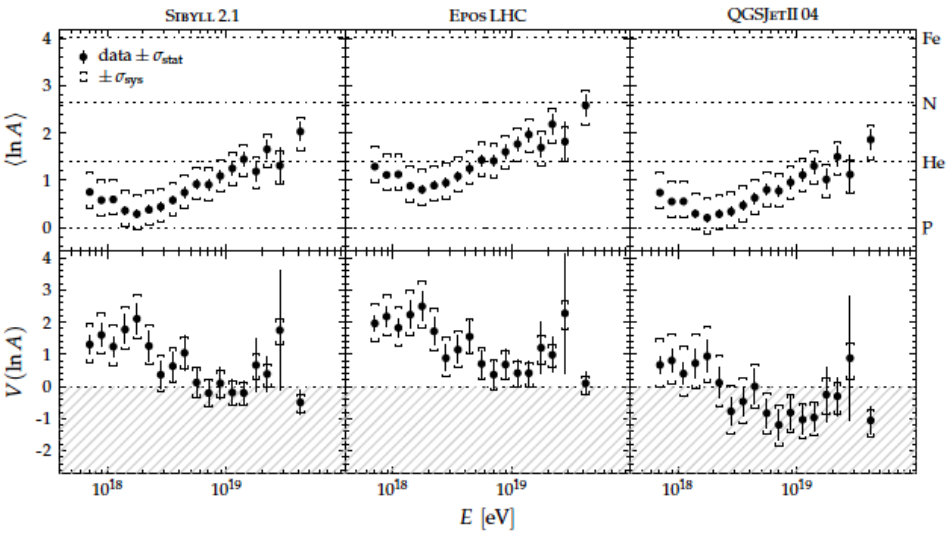


Figure 14: Average of the logarithmic mass and its variance estimated from data using different interaction models. The non-physical region of negative variance is indicated as the gray dashed region.

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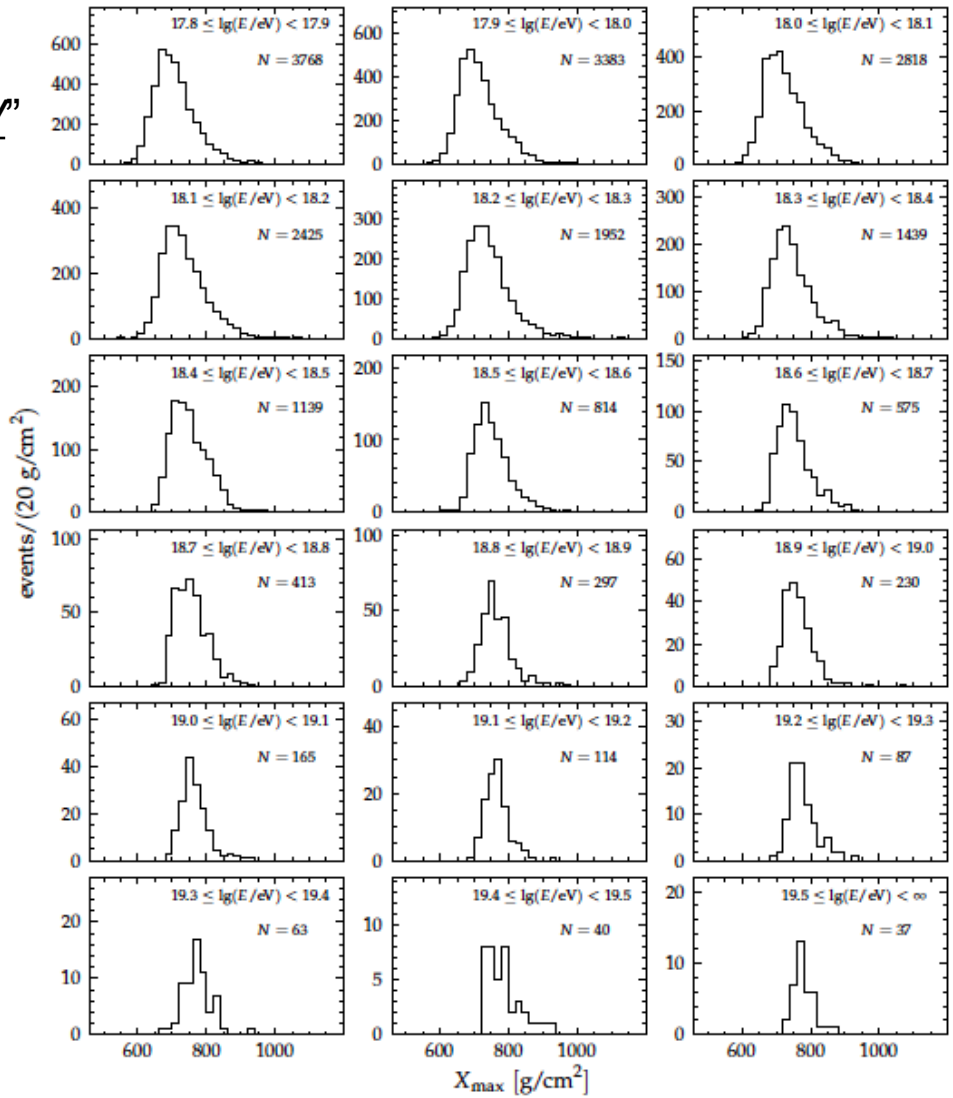

Figure 12: X_{max} distributions for different energy intervals.

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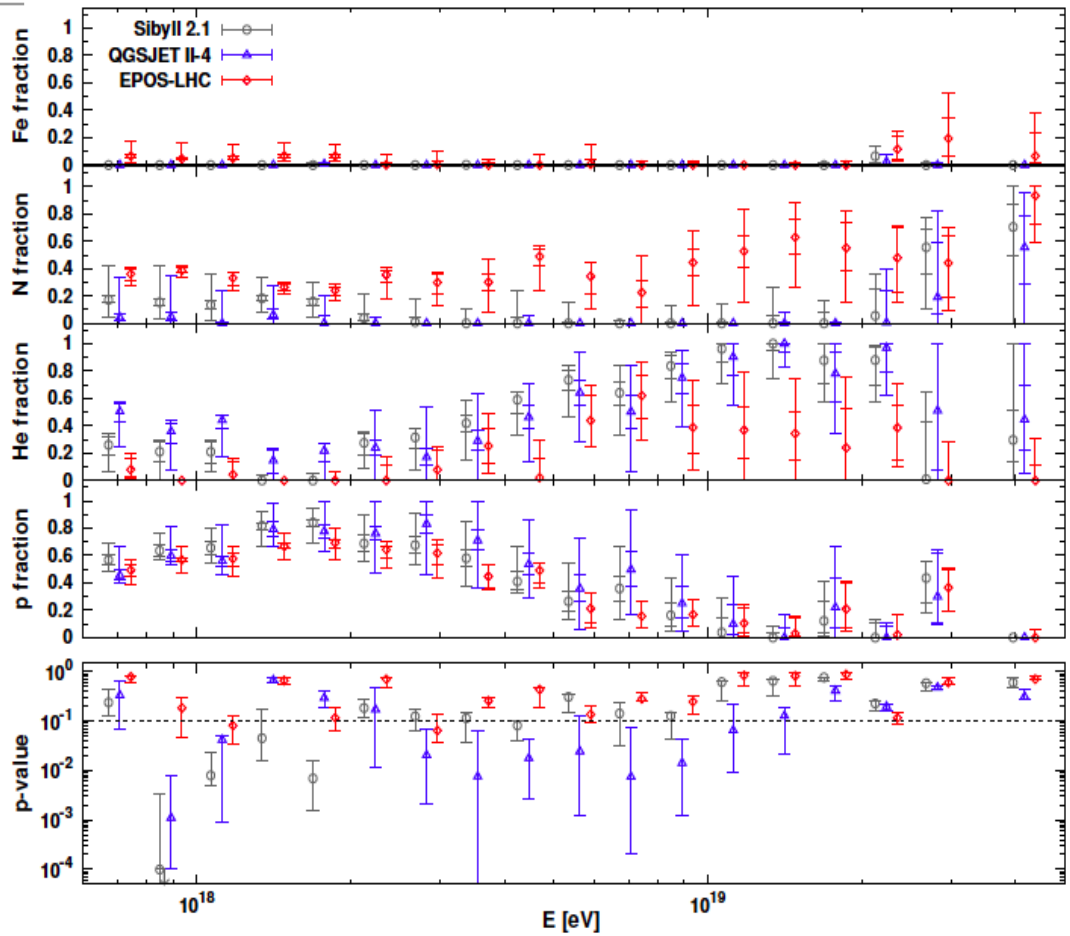


FIG. 4: Fitted fraction and quality for the scenario of a complex mixture of protons, helium nuclei, nitrogen nuclei, and iron nuclei. The upper panels show the species fractions and the lower panel shows the p-values.

Anisotropy

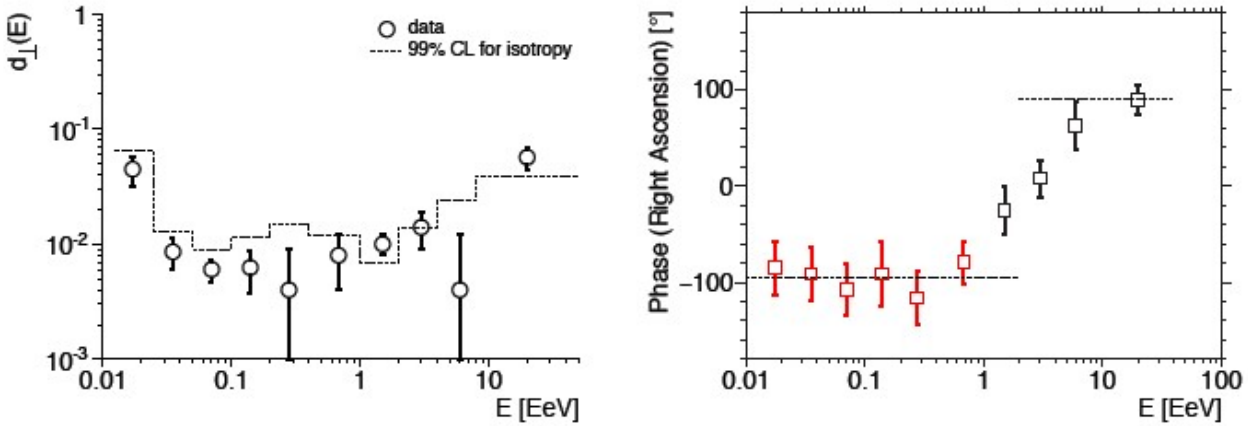


Figure 2.5: Large scale anisotropy search. Left: 99% limits on the dipole anisotropy in the equatorial plane for the collected statistics until end of 2014 (dashed line) and values of the dipole amplitude $d_\perp$. Right: estimated phase angles. The red points of the equatorial phase are from the analysis of the 750 m array. The data shown is an update of the analyses [15, 88], to be published at ICRC 2015.

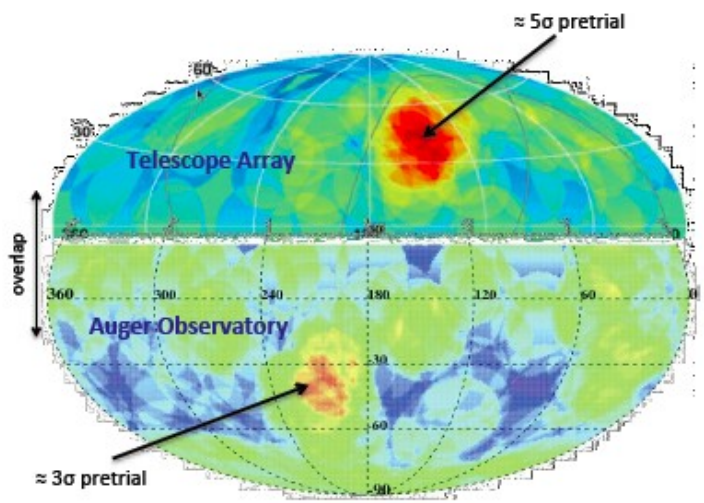
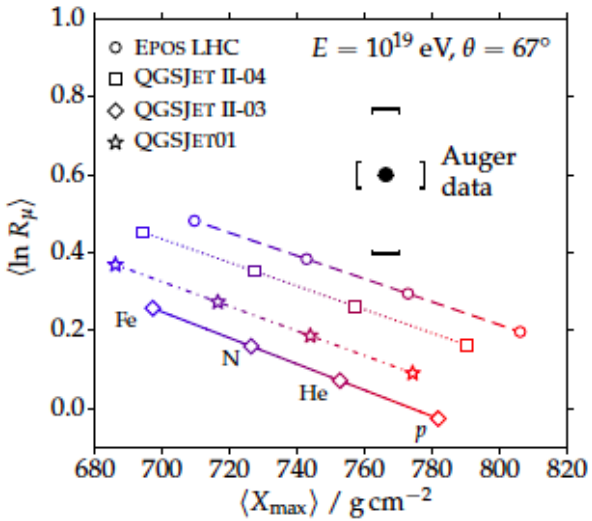


Figure 2.6: Regions of over-density observed after ~20°-smearing of the arrival directions of particles with $E > 5.5\times10^{19}$ eV. The results from the northern hemisphere are from the TA Collaboration [91].

Muons

HAS



Hybrid showers

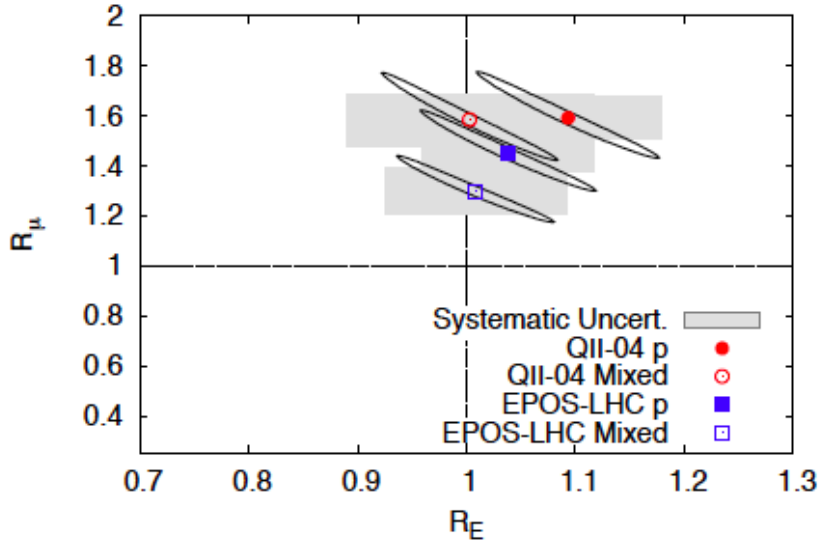


Figure 2.8: Left: Mean number of muons R_μ relative to that of proton reference showers, and depth of shower maximum at 10^{19} eV. The Auger data point [26], where the muon number is derived from inclined showers, is compared with predictions obtained from different interaction models. Right: Muon discrepancy [25] observed in showers of 10^{19} eV. Shown are the phenomenological scaling factors R_E and R_μ for the primary energy and the hadronic (primarily muonic) component of the shower that would be needed to bring a model calculation into agreement with Auger data, see text.

Muon excess 1.2-1.6 wrt predictions from hadronic interaction models