Pierre Auger Observatory

studying the universe's highest energy particles

Recent Results from The Pierre Auger Observatory and Some Statistical Issues

Banff, July 13, 2010

Paul Sommers

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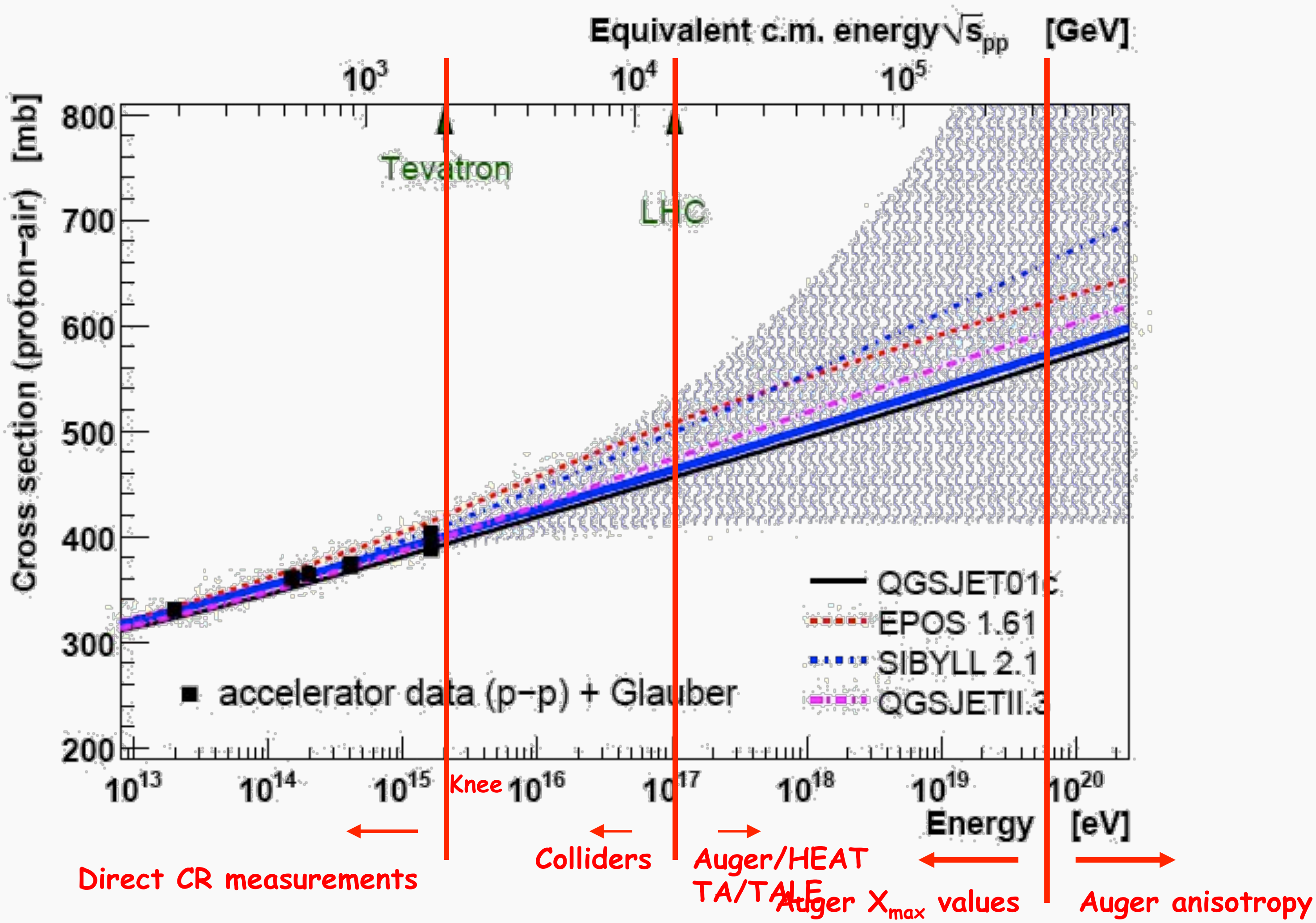
Energy Regimes



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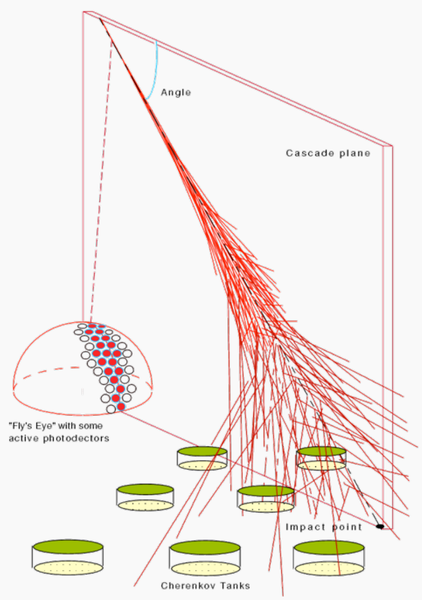
The Auger Observatory

One observatory in two hemispheres

Southern site completed June 2008

18 Participating Countries

Argentina	France	Portugal
Australia	Gemany	Slovenia
Bolivia	Italy	Spain
Brazil	Mexico	United States
Croatia	Netherlands	United Kingdom
Czech Republic	Poland	Vietnam



Hybrid shower measurements:

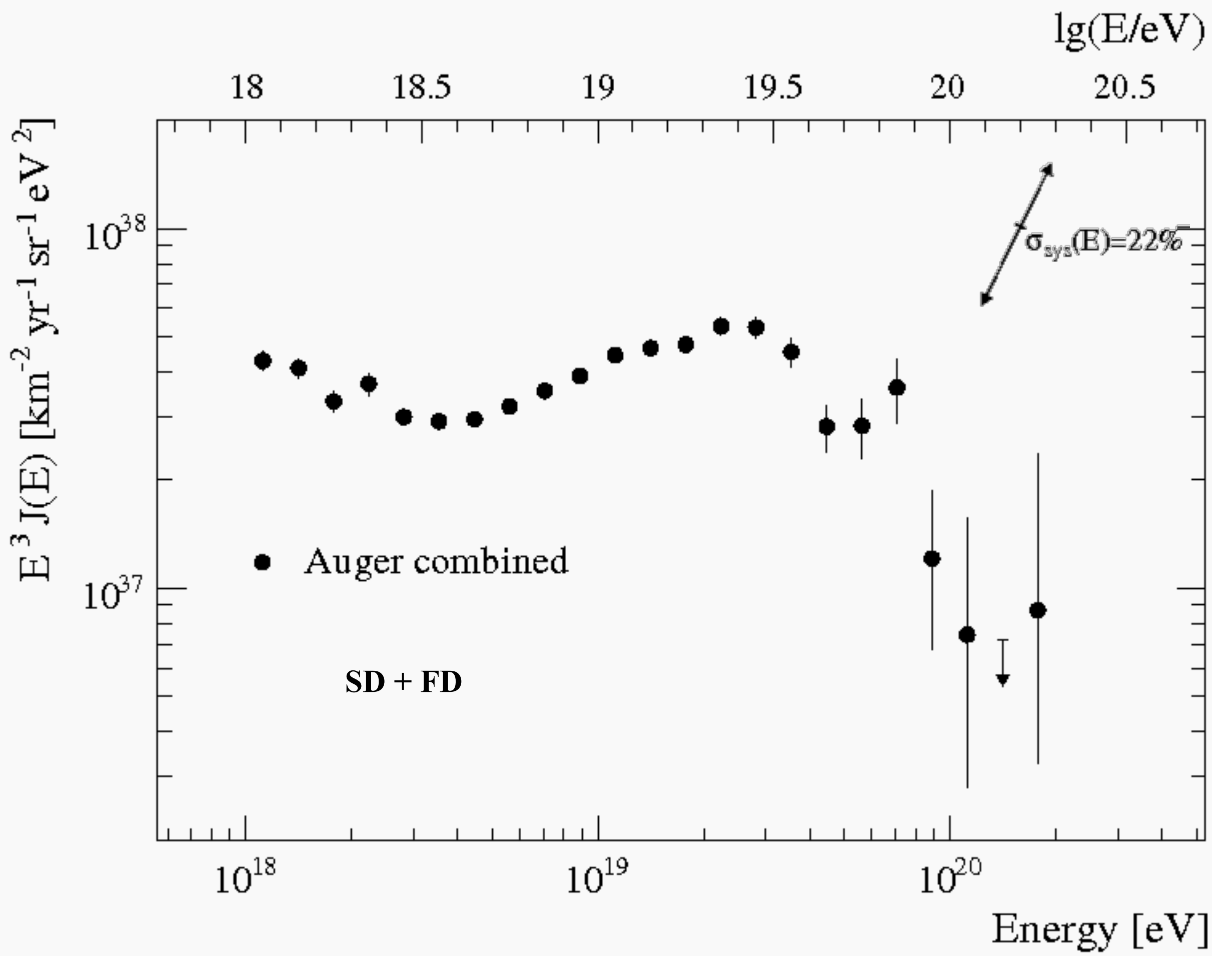
Surface array + air fluorescence

Spokesperson: Giorgio Matthiae

Founders: Jim Cronin and Alan Watson

The Energy Spectrum

The Auger Energy Spectrum



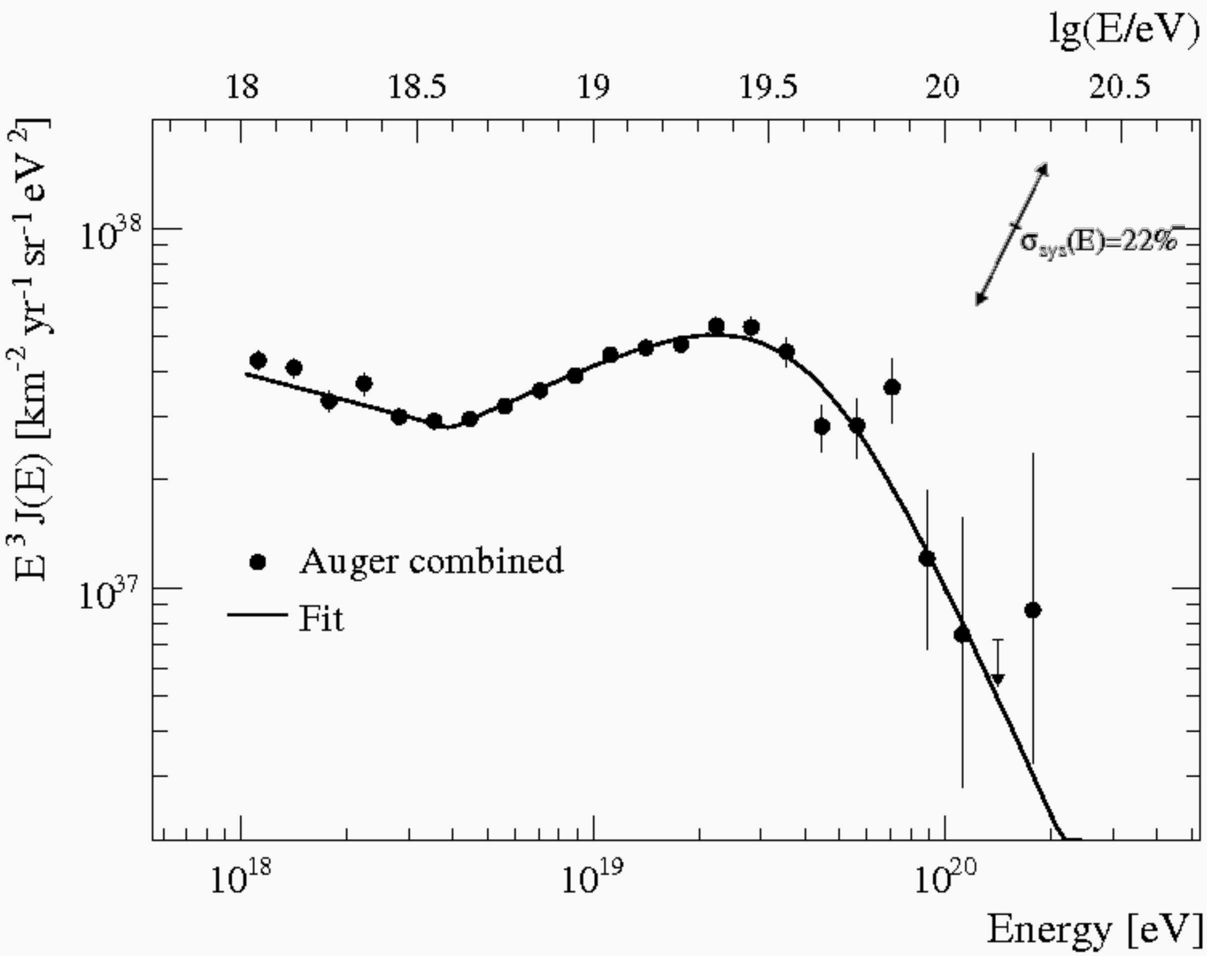
No serious statistical issues

Forward folding correction for energy resolution, steeply falling spectrum, and energy bins.

Unbinned likelihood analysis gives the same features

The deviation from a continuing power law above the ankle is now more than “10 σ” in the number count above $10^{19.4}$ eV (“GZK”)

The Auger Energy Spectrum

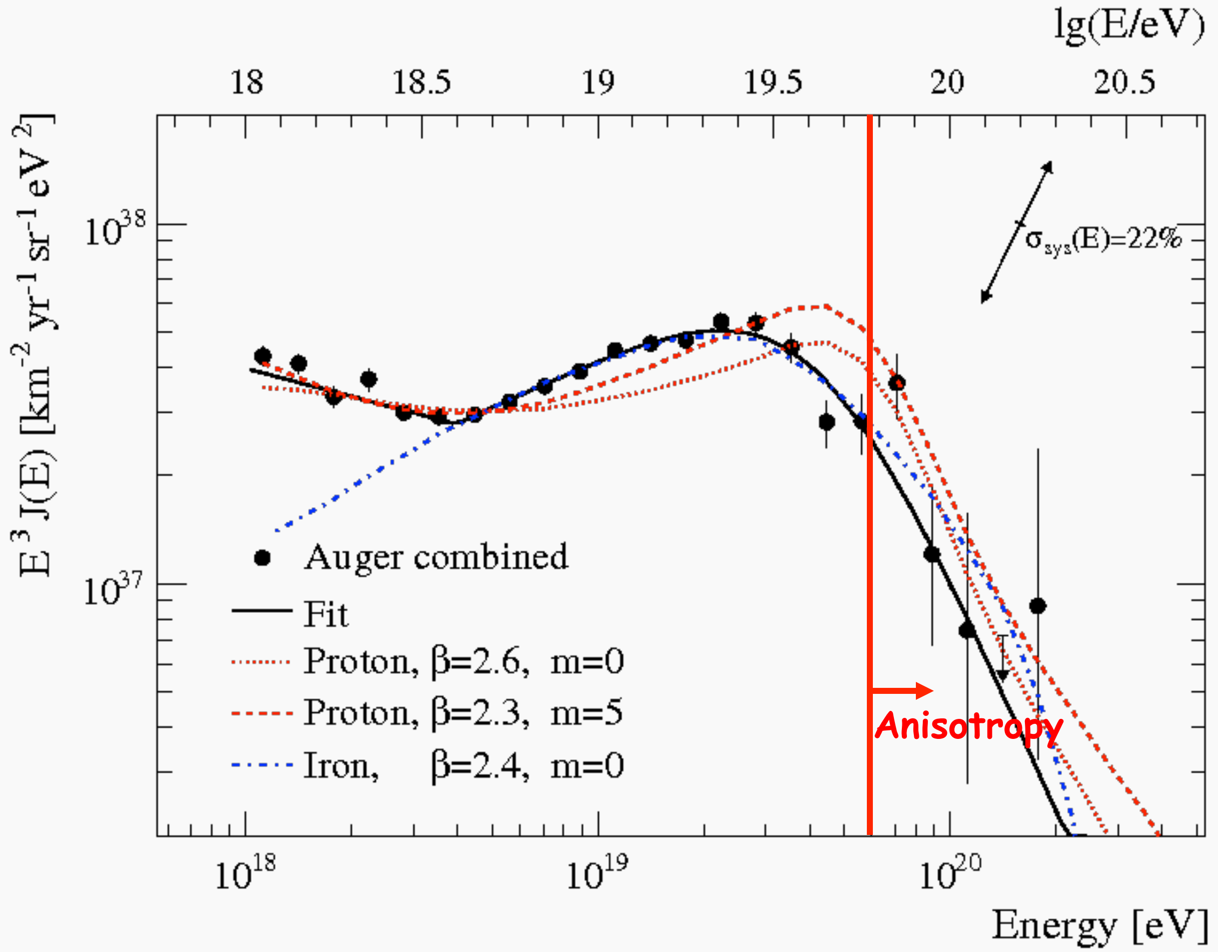


Schuessler

HE 0114

Five-parameter fit: index, breakpoint, index, critical energy, normalization

The Auger Energy Spectrum



Schuessler

HE 0114

Comparison with models

Anisotropy above 55 EeV
(1 EeV = 10^{18} eV)

The AGN correlation in 2007

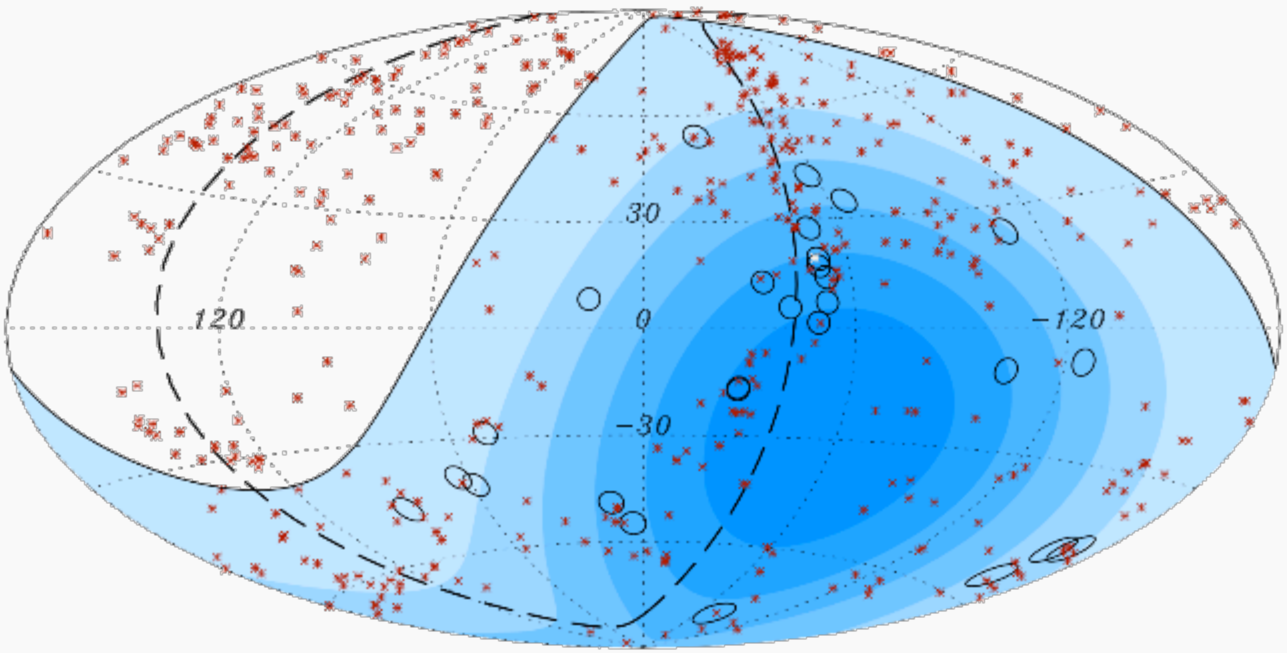


Figure 2: Aitoff projection of the celestial sphere in galactic coordinates with circles of radius 3.1° centered at the arrival directions of the 27 cosmic rays with highest energy detected by the Pierre Auger Observatory. The positions of the 472 AGN (318 in the field of view of the Observatory) with redshift $z \leq 0.018$ ($D < 75$ Mpc) from the 12^{th} edition of the catalog of quasars and active nuclei (*12*) are indicated by red asterisks. The solid line draws the border of the field of view (zenith angles smaller than 60°). Darker color indicates larger relative exposure. Each colored band has equal integrated exposure. The dashed line is, for reference, the super-galactic plane. Centaurus A, one of our closest AGN, is marked in white.

99% CL

Data prior to May 27, 2006, gave a high correlation (>70%) of arrival directions within 3.1 degrees of an AGN closer than 75 Mpc (using the incomplete VCV compendium). 21% expected for isotropy.

A single-trial test was prescribed for the next 34 events above the same energy threshold. Isotropy was the null hypothesis. The test used the same energy cut, same 3.1˚, same VCV catalog, same 75 Mpc. It was devised (ending at 34 events or earlier) such that the probability of exiting with a rejection of isotropy would occur in less than 1% of isotropic experiments, and in at least 95% of experiments if the true correlation rate is at least 60%.

Table 1
Criteria for our *running prescription* where N corresponds to the total number of events observed at any point during the *sequential analysis* of up to 34 events arriving with energy $E > 56$ EeV

N	4	6	8	10	12	···	30	31	33	34
$k_{\min}$	4	5	6	7	8	···	14	14	15	15

$k_{\min}$ is the minimum number of events within the angular window ($\psi = 3.1°$), and a maximum AGN redshift ($z_{\max} = 0.018$) required to reject isotropy with at least a 99% confidence level. This prescription applied to data collected after 27 May 2006 was satisfied with $N = 8$ and $k = 6$ on 25 May 2007.

Update 2010

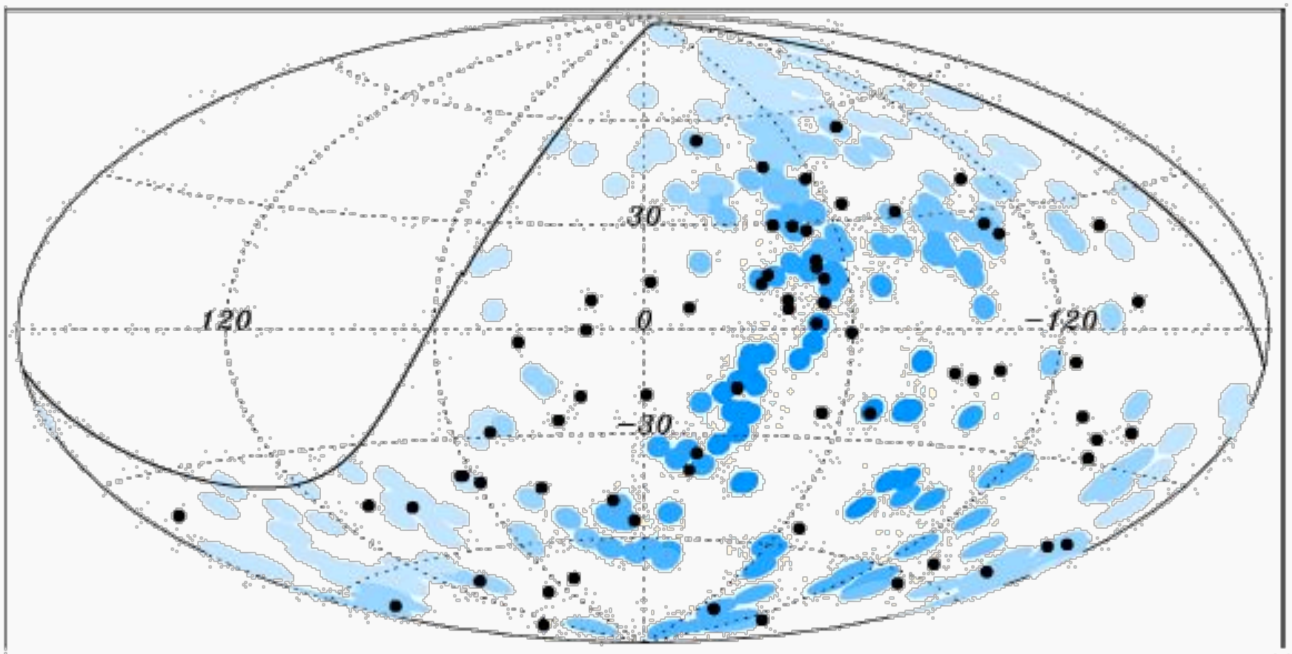
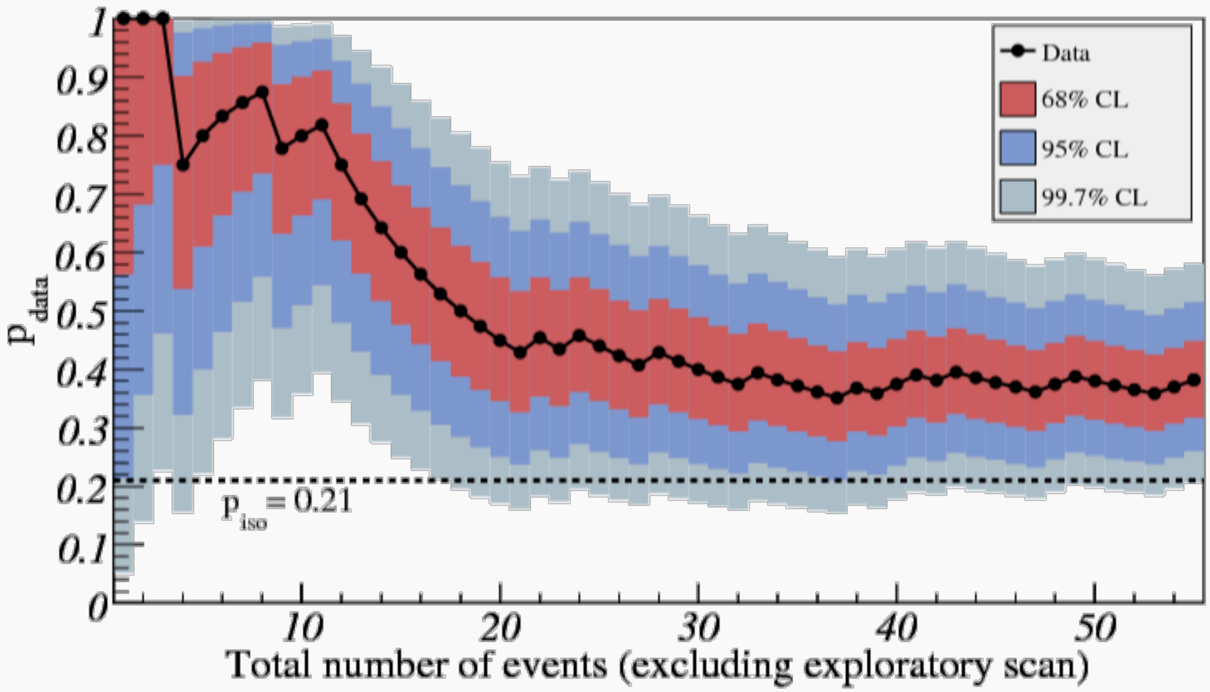


Figure 1. The 69 arrival directions of CRs with energy $E \geq 55$ EeV detected by the Pierre Auger Observatory up to 31 December 2009 are plotted as black dots in an Aitoff-Hammer projection of the sky in galactic coordinates. Blue circles of radius 3.1° are centred at the positions of the 318 AGNs in the VCV catalog that lie within 75 Mpc and that are within the field of view of the Observatory. Darker blue indicates larger relative exposure. The exposure-weighted fraction of the sky covered by the blue circles is 21%.

Correlating fraction versus time



Best estimate of correlating fraction is now 38%

P=0.003

Remarks

The correlating fraction is less than was previously estimated.

Despite more than doubling the data, the significance (as measured by the P-value) has not increased much.

Based on what we know now, the rejection of isotropy was not likely.

The 5-sigma advocates can say I told you so. But 99% CL folks had reasons.

The correlating fraction has fluctuated.

Is there statistical evidence that the detector changed?

Despite extensive study, no other evidence of a relevant change in the detector has been found.

The correlating rate has been steady; the non-correlating rate has increased.

The AGN correlation, now 38%, is substantially above the 21% expected for isotropy. But what does it mean?

The VCV catalog is incomplete and inhomogeneous. More suitable catalogs now exist (e.g. Swift-BAT, 2MRS)

Comparison with the Swift-BAT AGN catalog

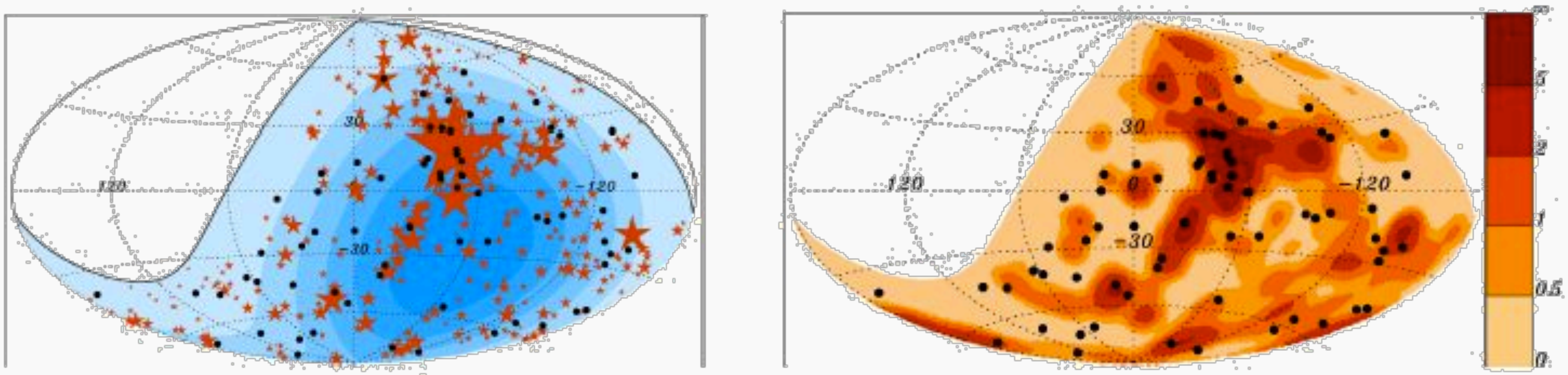


Figure 4: Left: Sky map in galactic coordinates with the AGNs of the 58-month Swift-BAT catalog plotted as red stars with area proportional to the assigned weight. Right: density map derived from the map to the left, smoothed with an angular scale $\sigma = 5°$. The 69 arrival directions of CRs with energy $E \geq 55$ EeV detected with the Pierre Auger Observatory are plotted as black dots.

Excess in the Cen A region

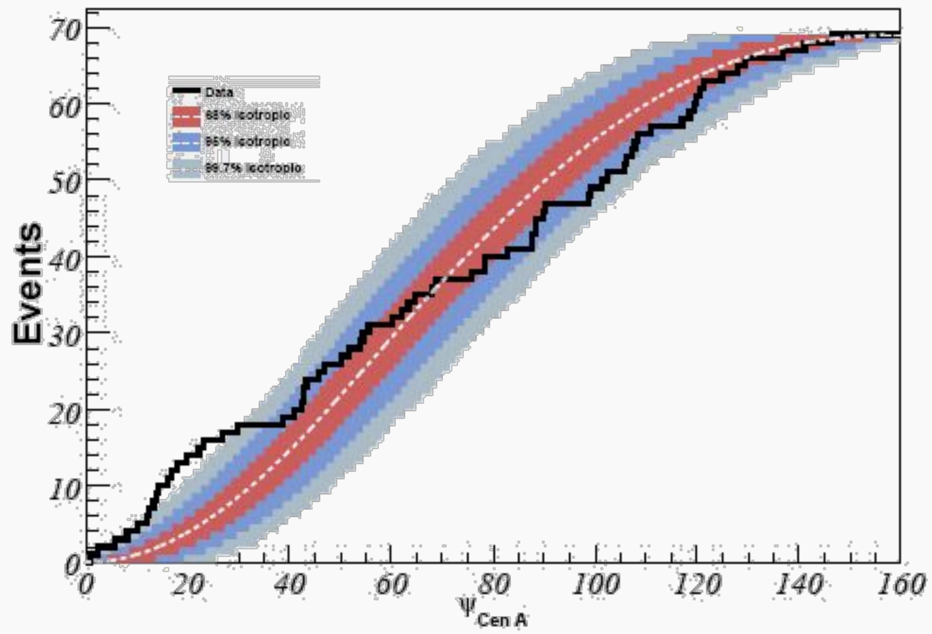


Figure 8: Cumulative number of events with $E \geq 55$ EeV as a function of angular distance from the direction of Cen A. The bands correspond to the 68%, 95% and 99.7% dispersion expected for an isotropic flux.

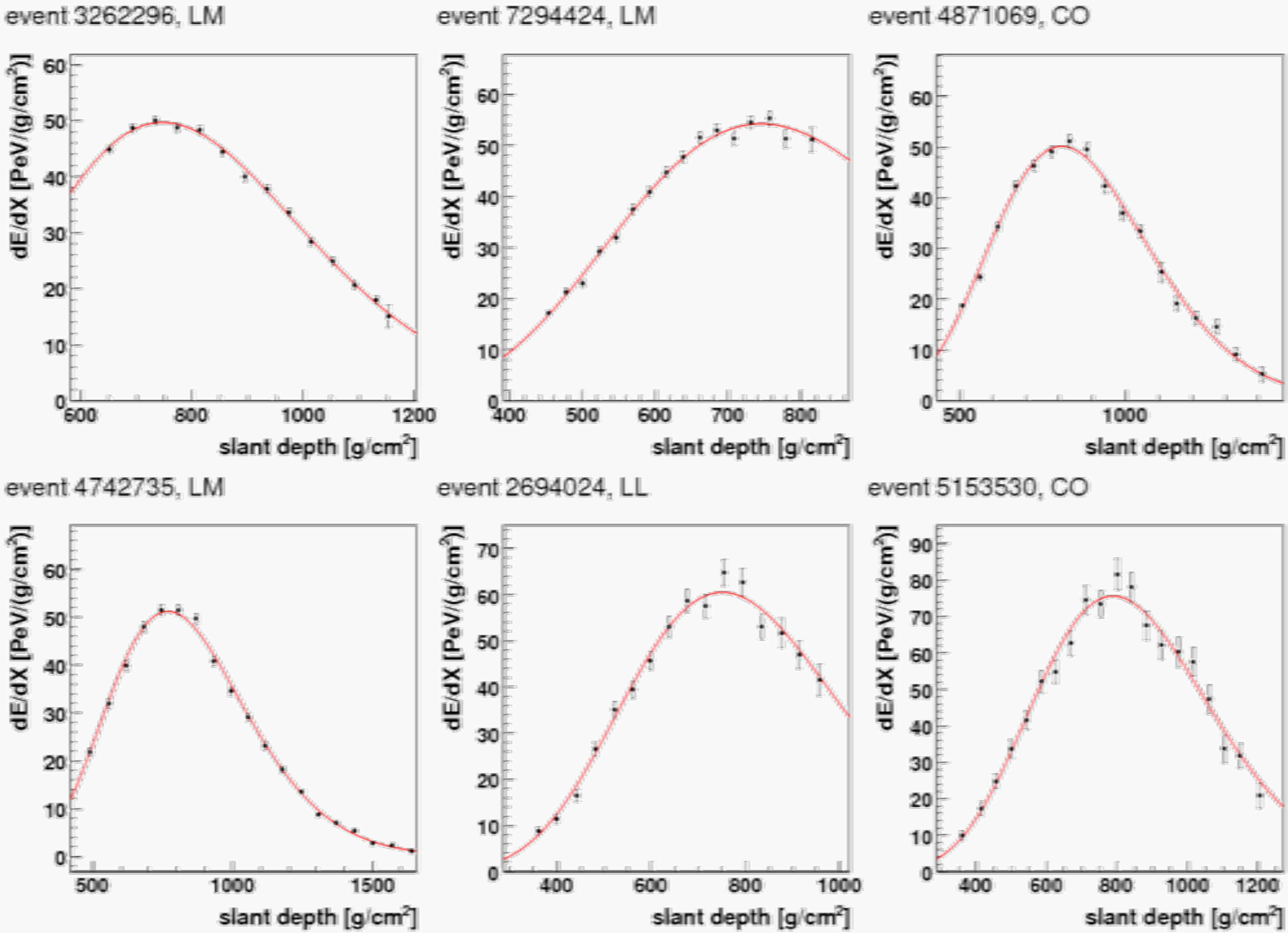
Distance to Cen A is only 3.5 Mpc

Distance to the Centaurus supercluster (behind) is 55 Mpc

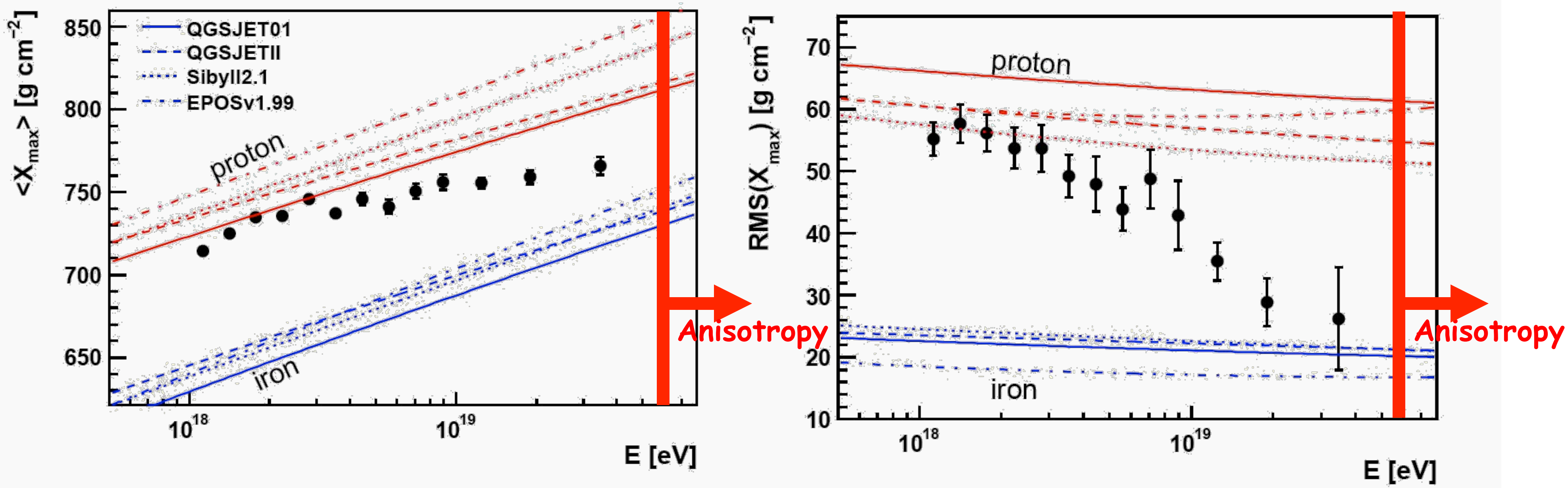
Auger

Air shower development speeds

Reconstructed longitudinal profiles



Shower Depths of Maximum X_{max}



These suggest high cross section and high multiplicity at high energy.

Heavy nuclei?

Or protons interacting differently than expected?

Information lacking for the (anisotropic) trans-GZK energy regime!

(Crucial for calculation of the diffuse cosmogenic neutrino flux)

Remark

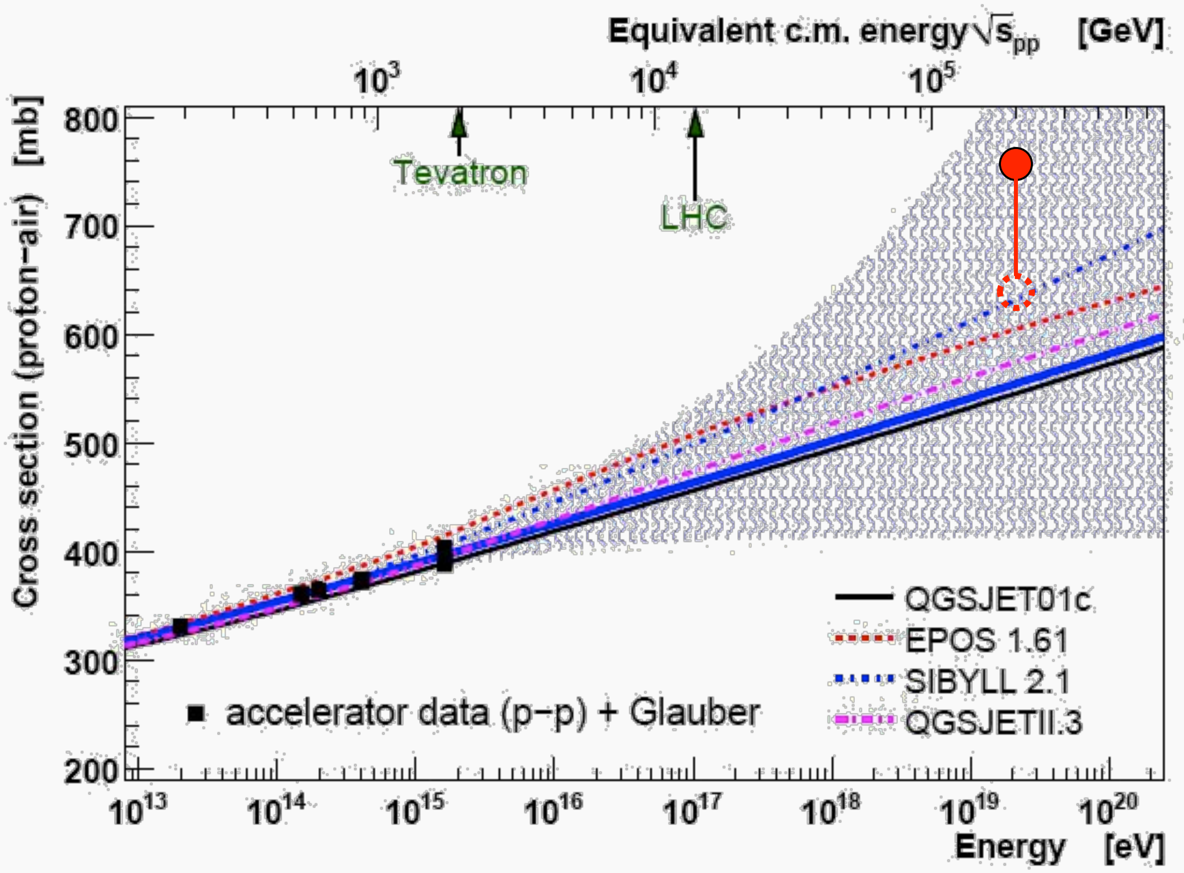
Arrival directions of heavy nuclei (Z=26 for iron) should typically be deflected by at least 50 degrees coming to the plane of the Galaxy through the magnetic fields in the disk.

The apparent anisotropy cannot be expected if the particles are highly charged.

Could it be that hadronic interactions are very different from customary extrapolations from energies where experiments have measured their properties?

Is it plausible that cross section, inelasticity, and multiplicity are high enough for a proton air shower to resemble what is expected for an iron air shower?

Lower bound on the p-air cross section if the primaries are protons



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Other stuff

Neutrino flux upper limits (none observed so far)

Gamma ray flux upper limits (limited number of candidates)

Neutron point source upper limits (variety of energy ranges)

- Interesting celestial positions
- Sky map

Upper limits on large scale anisotropy (e.g. dipole) at EeV energies

Sur la piste des rayons cosmiques dans la pampa argentine

Quelle est l'origine des **rayons cosmiques** *? C'est pour résoudre cette* **énigme** *que des chercheurs ont investi la pampa argentine. Là, ils ont installé* **le plus grand détecteur** *du monde qui, jour et nuit, traque les* **flux de particules** *venues du* **cosmos**. *Une* **quête** *dont les physiciens espèrent beaucoup.*

Cette cuve perdue dans la pampa (à dt) détecte la trace des rayons cosmiques.

Par Claire Martin. Photos: Rodrigo Gomez Rowira/Vu

http://auger.cnrs.fr/presse/SV_Auger.pdf