The Pierre Auger Observatory, latest results

Xavier Bertou

Centro Atómico Bariloche. Argentina

Third School on Cosmic Rays and Astrophysics, Arequipa, Perú, 1st September 2008


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studying the universe's highest energy particles
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While cosmic rays with low to moderate energies are well
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Southern Observatory
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Introduction to the Pierre Auger Observatory
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Air shower means "particle cascade"

An energetic cosmic ray collides with air nucleus and produces lots of secondary particles. (See image of a particle collision in the Star detector at RHIC.) Each of them produces more particles. An energetic air shower can have many billions of particles at ground level.

Why not measure the cosmic rays directly?

At 10^{19} eV (1.6 Joule) the rate is 1 cosmic ray per year per square kilometer!

Satellite and balloon payloads are far too small to make measurements.

Take advantage of the atmosphere. Use it as transducer and amplifier.

For high energy cosmic ray observations (unlike conventional astronomy) the atmosphere is a blessing, not a curse.

The billions of secondary particles are easy to detect.

The Auger Observatory, for example, measures every high energy cosmic ray that arrives in a 3000 km^2 area in Argentina (an area equal to that of Rhode Island).

The challenge is to "reconstruct" the properties of the primary cosmic ray by detecting some of the secondaries.

The properties we want to measure are

Arrival direction

Energy

Particle type, mass

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- Energy
- Particle type, mass

- Spectrum
- Photon/Neutrino limits
- “AGN” correlation

Towards a big picture?

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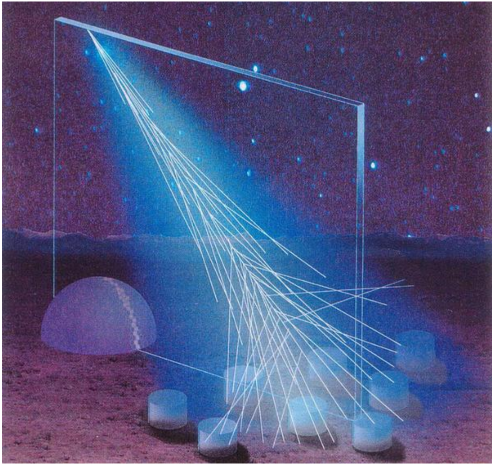

Detector

- Fluorescence Telescope
- Ground Array

EAS at 10^{20} eV

- 50 W light bulb at speed of light
- 10^{12} particles spread over >20 km^2

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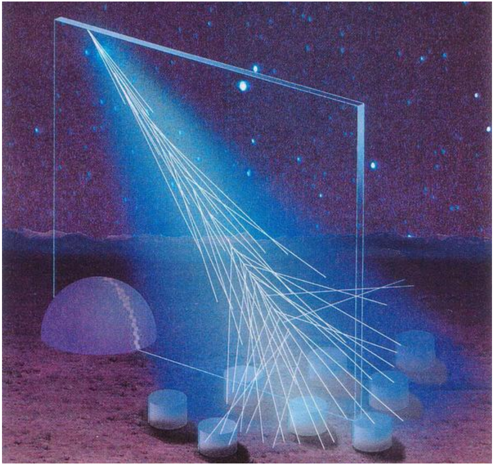

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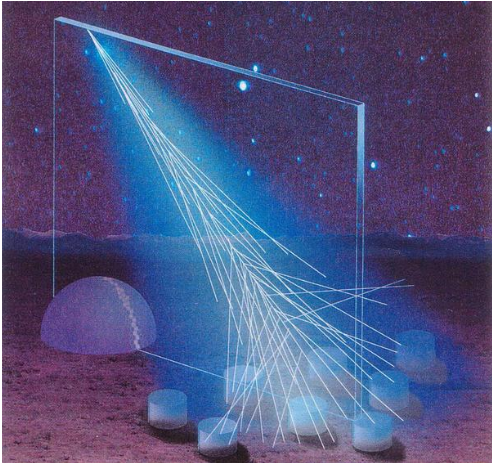

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Station 1600 installed in May 2008
> 1600 stations sending data on 28 August 2008

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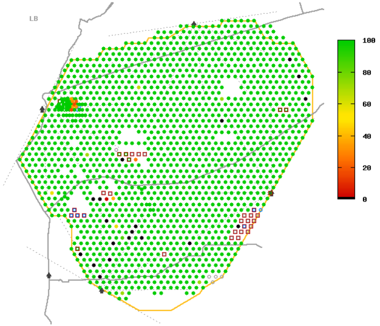

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Outline

1. Spectrum
   - Basics
   - Get signal from event
   - Energy calibration
   - Results
2. Photon/Neutrino limits
   - Why look at γ/ν
   - FD photon limit
   - SD photon limit
   - Neutrino limit
3. "AGN" correlation
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Determining UHECR spectrum

What do we need?

- Get Energy for each event
- Get Aperture (surface, solid angle, time)

Very low fluxes

Need for high statistics: use SD data

At lower energy?

High statistics but...
Not full acceptance

Use alternatives

Infill array (750 m or 433 m)
Hybrid events (need only one station)

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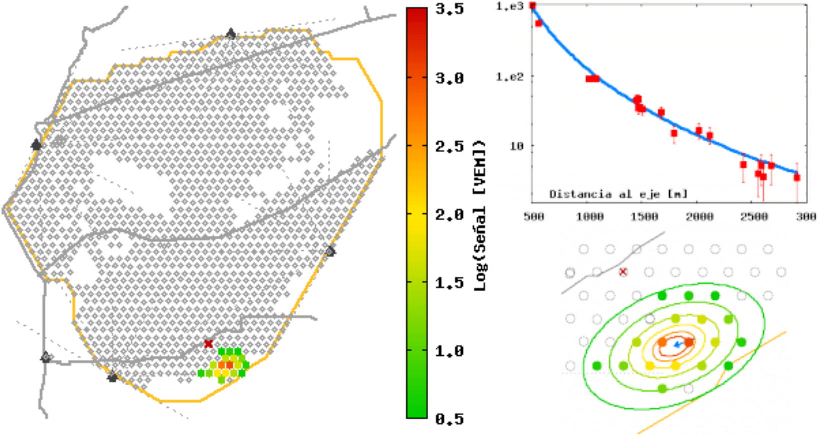

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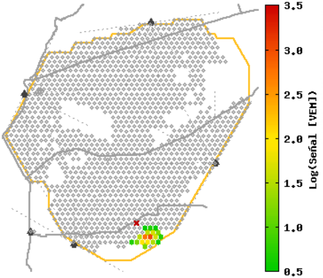

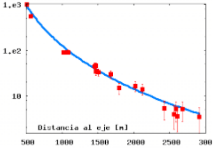

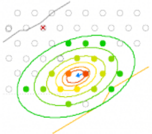

Signal at 1000 m: S(1000)

Little influenced by:

- point of first interaction (close to the core)
- statistical fluctuations (far to the core)
- change in LDF slope (geometric property)

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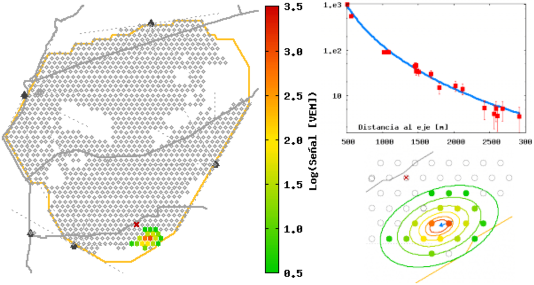

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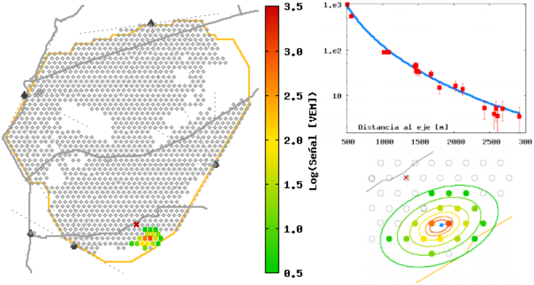

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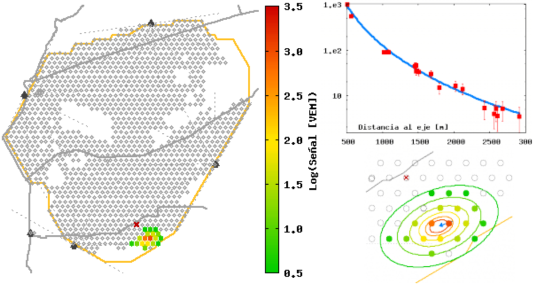

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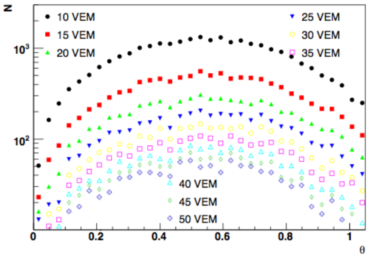

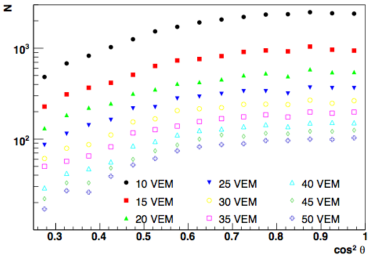

Zenith angle

Atmosphere roughly in $1/\cos\theta$

Constant Intensity Cut (CIC)

Determine an equivalent reference signal at 38 degrees S_{38}

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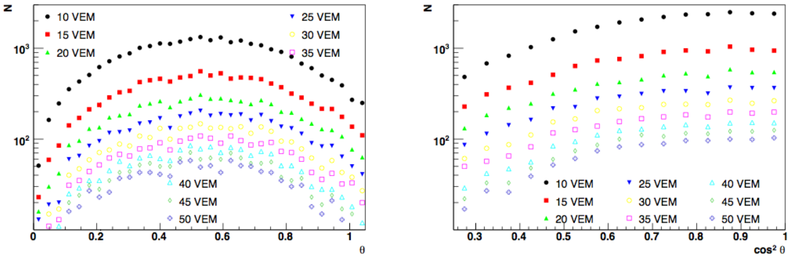

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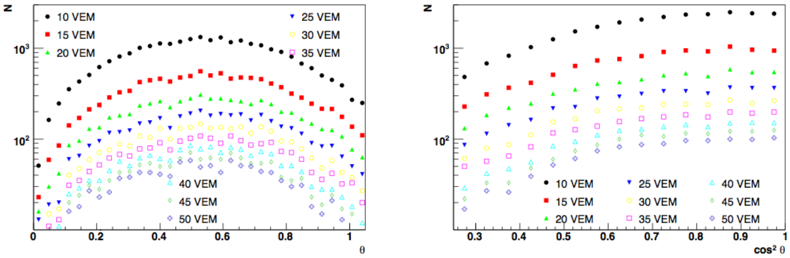

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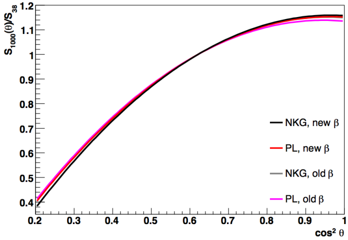

S_{38} to Energy with FD

Simple fit of a power law

$$E = A \times S_{38}^{B}$$

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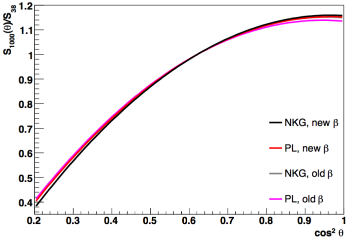

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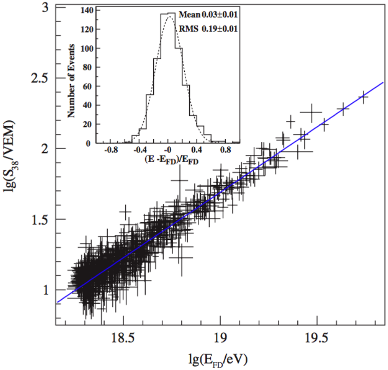

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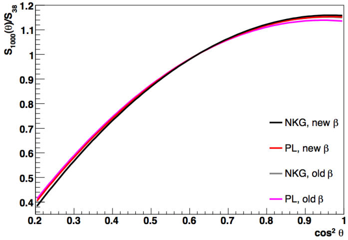

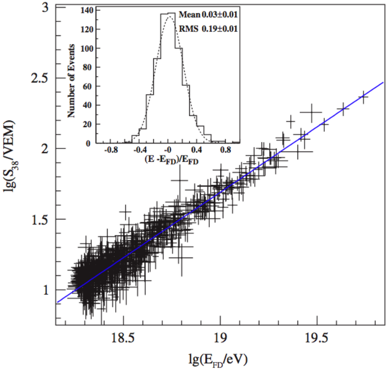

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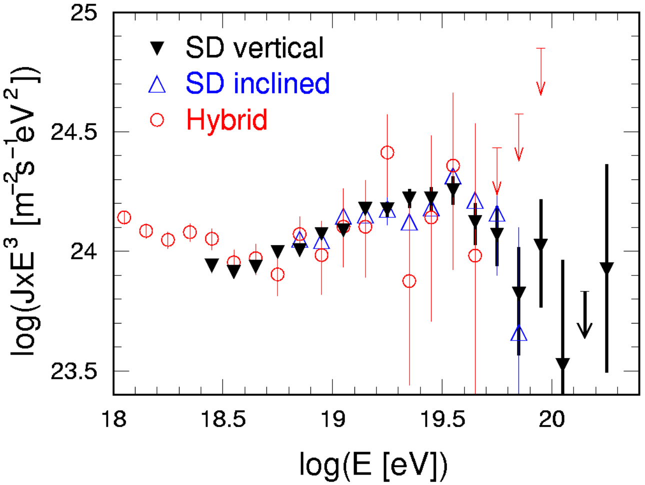
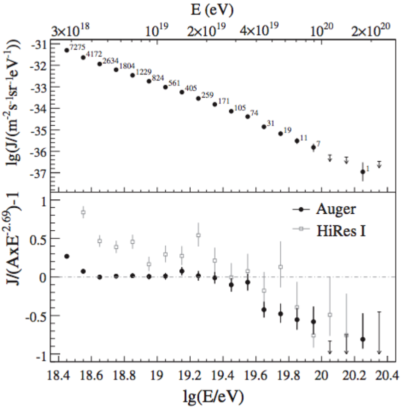
Auger Spectrum (ICRC August 2007)



Latest Auger Spectrum



PRL 101, 061101 (2008): *Observation of the Suppression of the Flux of Cosmic Rays above 4×10^{19} eV*

6σ statistical suppression

Energy	Expected	Observed
$> 4 \times 10^{19}$	167 ± 3	69
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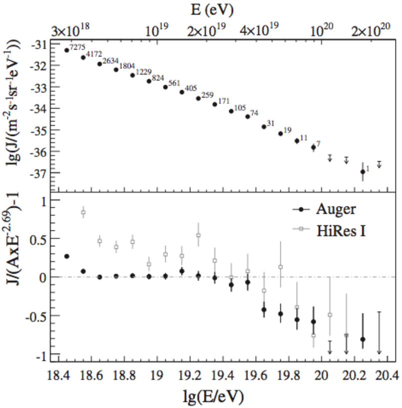

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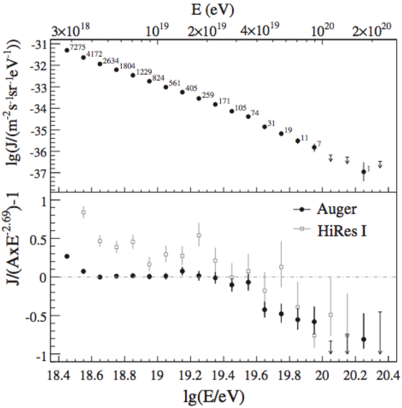

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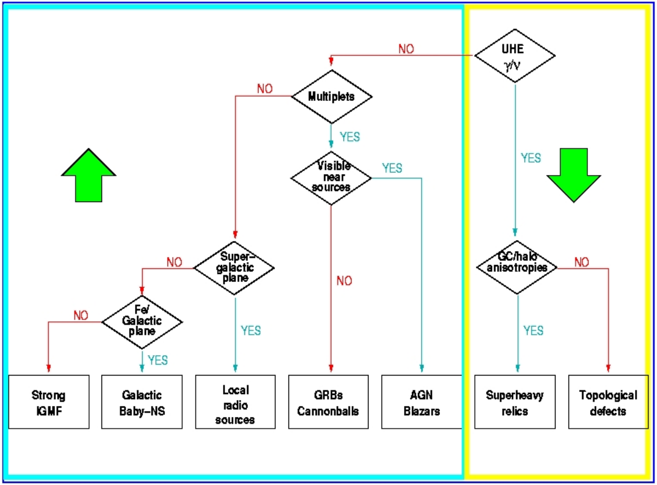
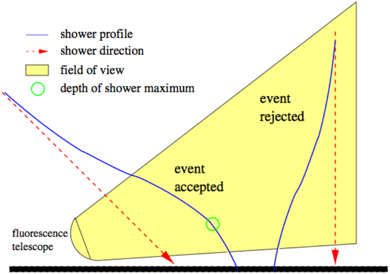
Why look at photons/neutrinos: the Model Killer



Use X_{max} with FD for photons



Derive upper-limit for photon flux above 10^{19} eV at 95% CL

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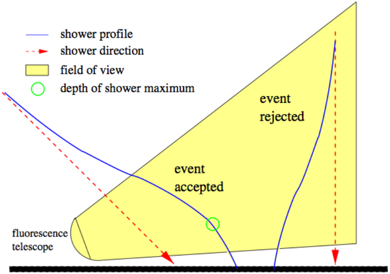

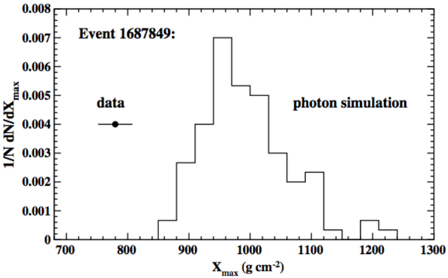

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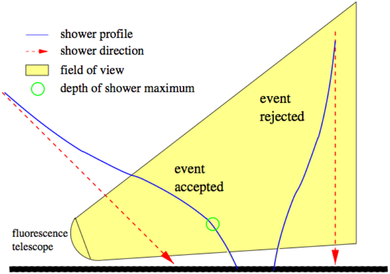

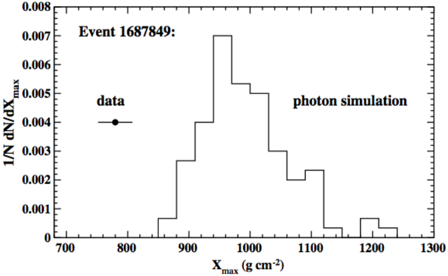

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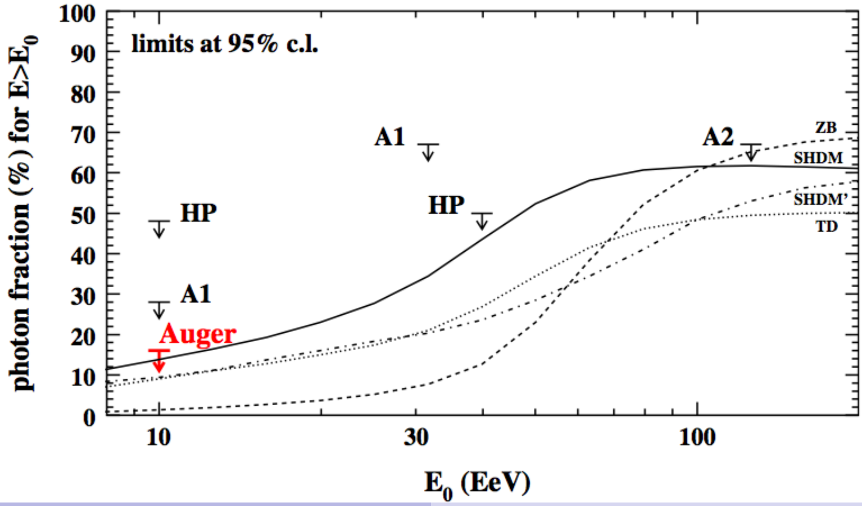
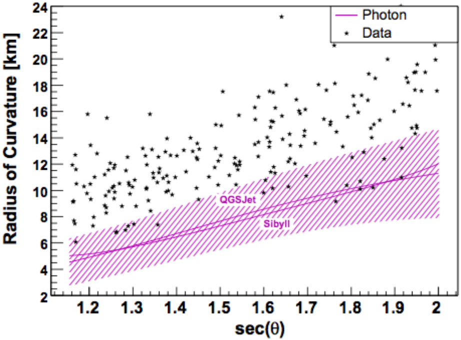
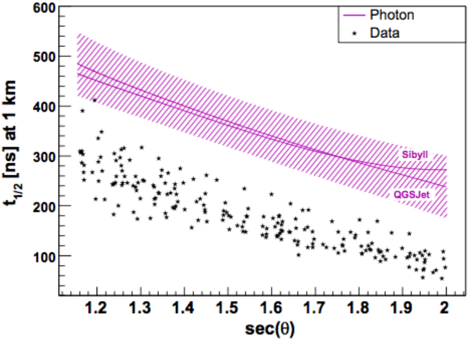
FD limit: Astroparticle Physics 27 (2007) 155-168



Use SD statistics to improve limits





Principal component analysis using both parameters to extract 95% CL limits for a 50% photon selection efficiency

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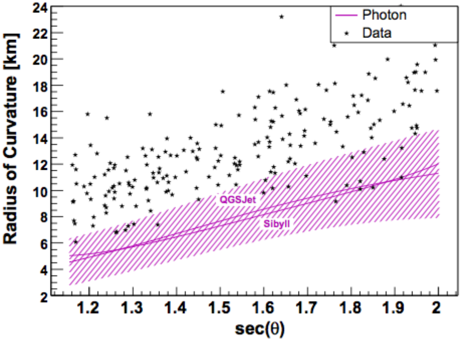

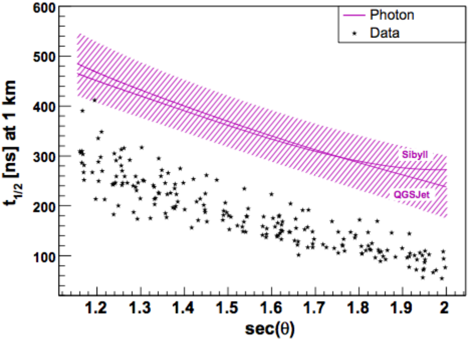

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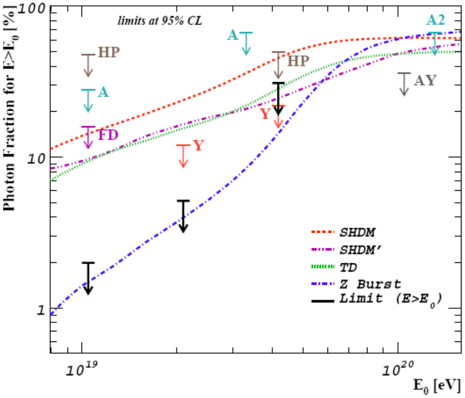
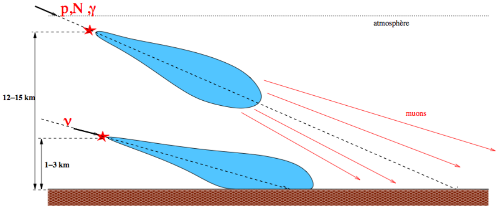
SD limit: Astroparticle Physics 29 (2008) 243-256



No photons: Top-Down models strongly constrained

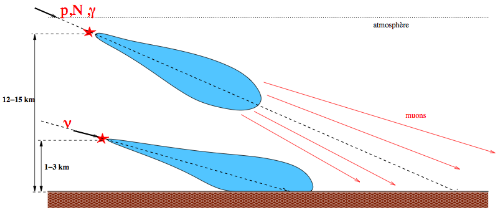
Neutrinos

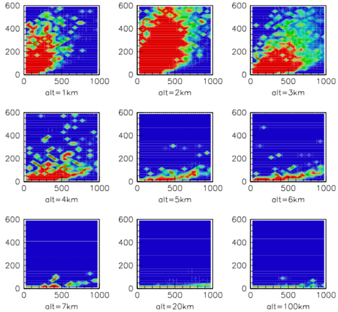


Idea

Detect horizontal showers, to discriminate from ordinary CR

Neutrinos



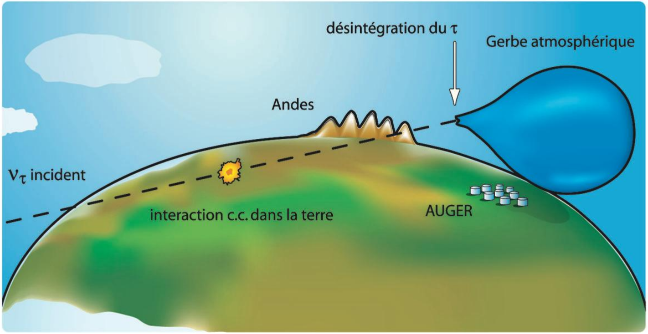


Signal versus time at 10^{19} eV

Idea

Detect horizontal showers, to discriminate from ordinary CR

Tau Neutrinos



Earth crust 200 km
Auger size 60 km

ν_τ interaction length 50 km
ν_τ decay length 30 km

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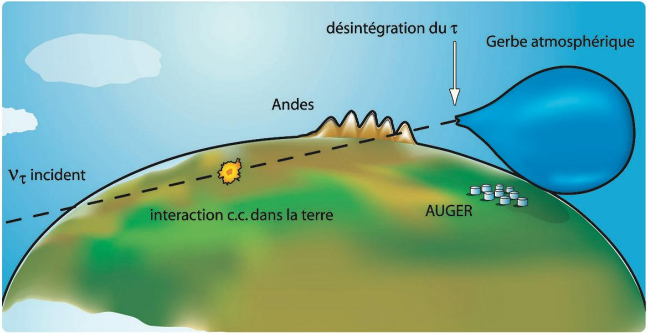

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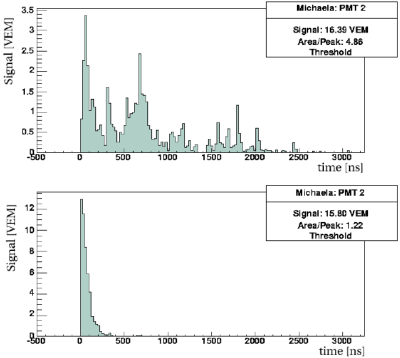

Still no Neutrino

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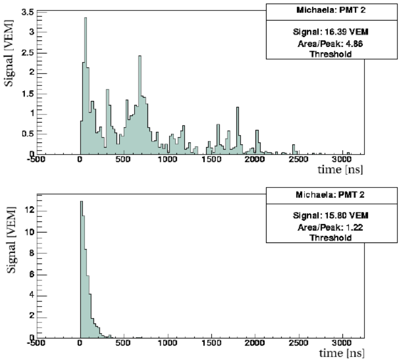

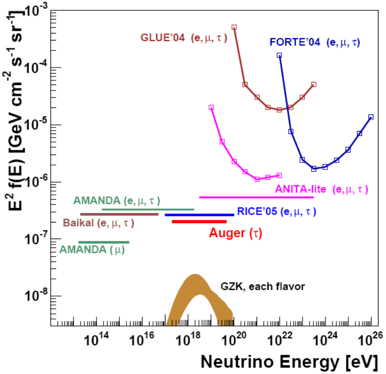

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Outline

Looking for the sources at UHE

Why?

- No magnetic deflections
- GZK: close-by sources only
- Close-by Universe is anisotrope

Auger Results

- GZK at 6 σ
- No Photon/Neutrino
- Astrophysics Bottom-Up models favoured

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Possible Method

- Choose your favorite catalogue
  ex: Veron Veron-Cetty 12^{th} edition of AGN
- Scan in energy, angular separation, maximum distance
  ex: E>40 EeV, $1\,\mathrm{deg} < \delta\alpha < 8\,\mathrm{deg}$, $d < 100$ Mpc
- Look for minimum and penalize for scan

May 26 2006

- 12 events out of 15 correlate for
  $\delta\alpha < 3.1\,\mathrm{deg}$, $z < 0.018$ ($d < 75$ Mpc), E>56 EeV
- 3.2 expected
- Penalized probability: 10^{-3}

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May 26 2006

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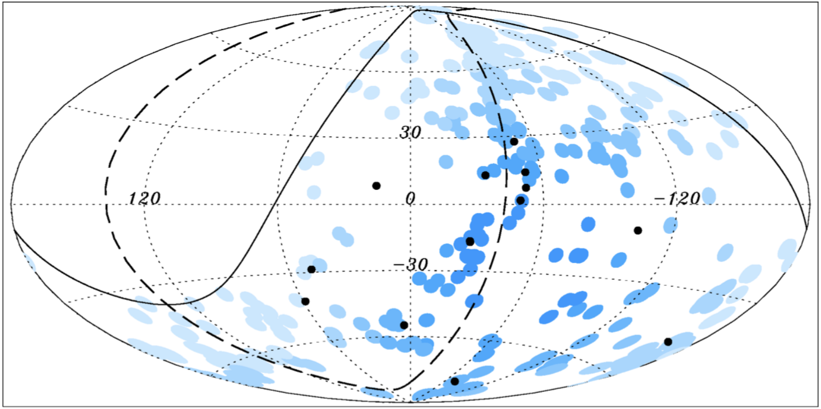
  $\delta\alpha < 3.1\,\mathrm{deg}$, $z < 0.018$ ($d < 75$ Mpc), E$>$56 EeV
- 3.2 expected
- Penalized probability: 10^{-3}

Status on May 26 2006



Auger Prescription

- Keep looking with these parameters until we can reject the isotropy hypothesis at 99% CL.
- May 28 2007: 6 out of 8 new events correlate
  Prescription passed

UHECR are anisotrope

Confirmation at 99% CL that UHECR are anisotrope with an independant data set

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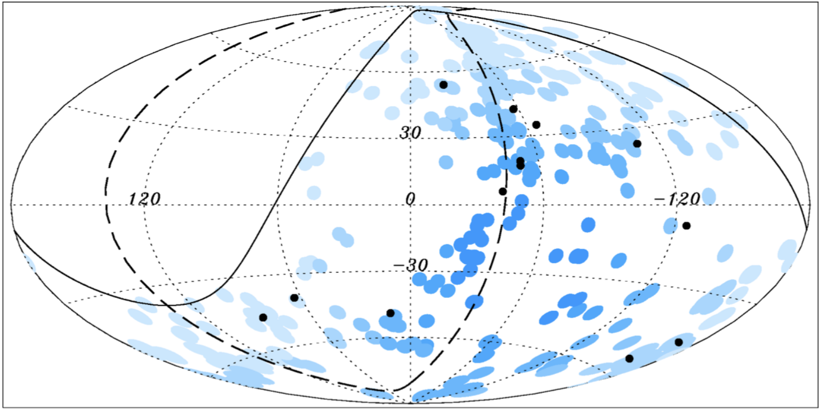
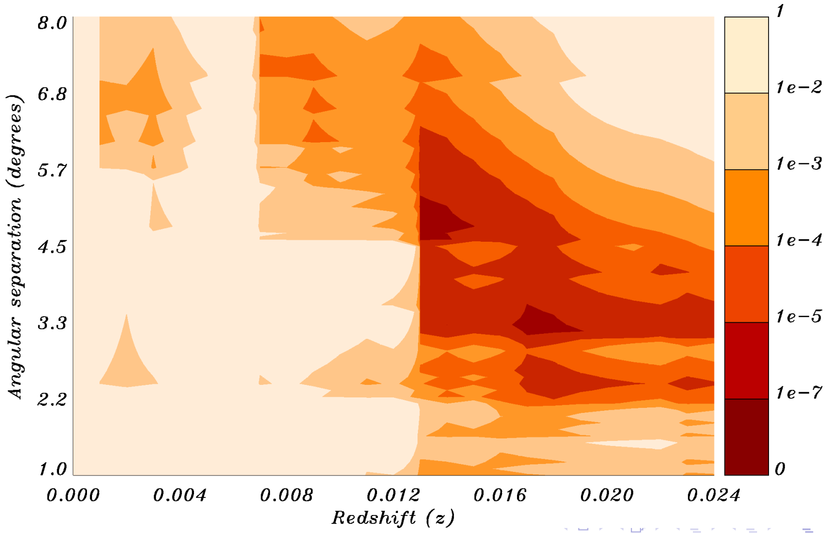


Correlation with close-by AGNs



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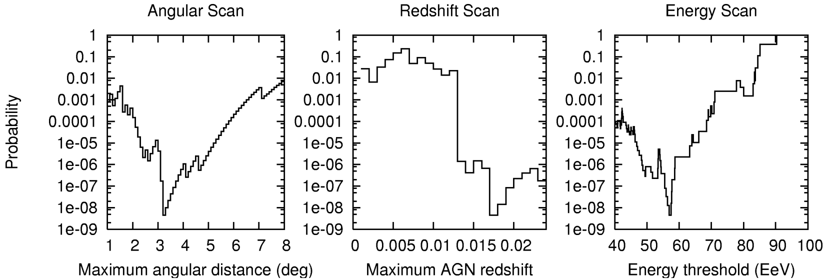

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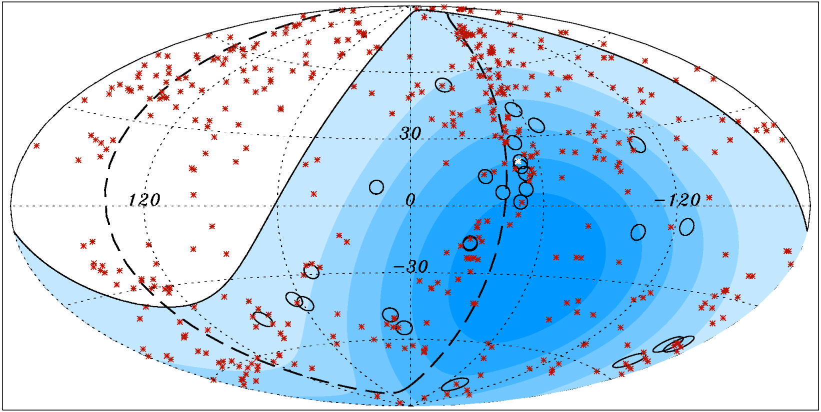

Current Correlation with close-by AGNs

Parameters minimizing the chance probability

- $\delta\alpha < 3.2\,\mathrm{deg}$
- $z < 0.017$ ($d < 71$ Mpc)
- E$>$57 EeV

20 out of 27 correlate, penalized probability: 10^{-5}

Another local minimum

$\delta\alpha < 4.8\,\mathrm{deg}$, $z < 0.013$ ($d < 55$ Mpc), E$>$57 EeV
Penalized probability 2×10^{-5}

Galactic plane cut

Cutting at 12 degrees around Galactic Plane:
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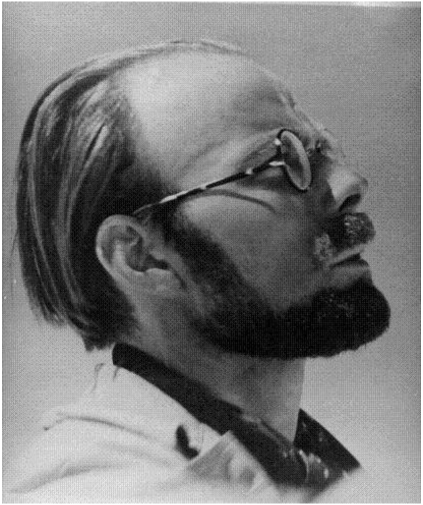
Outline

The Big Picture



The Big Picture

UHECR are produced by closeby astrophysical objects

No photon/neutrino

Flux suppression at about GZK energy

“AGN” correlation

“AGN” correlation implies small deflections: primary should be protons

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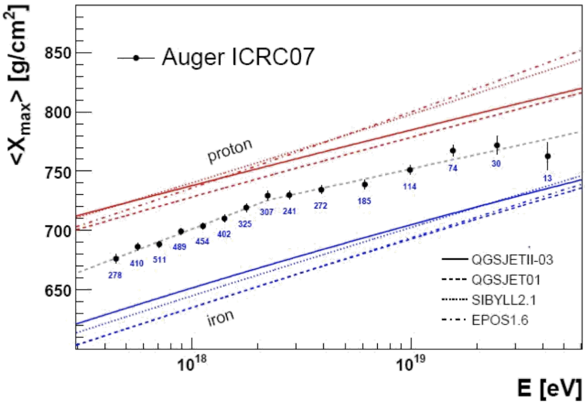

UHECR seems to get heavier

Change in particle physics?

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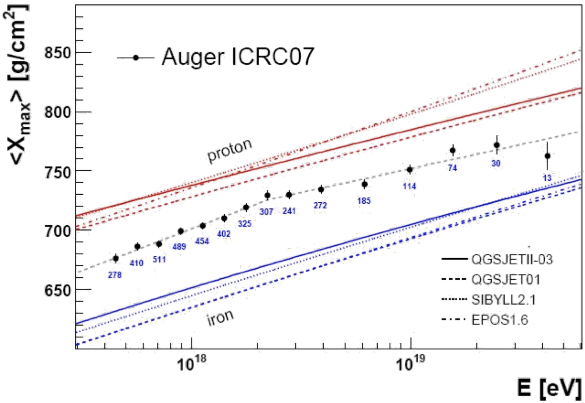

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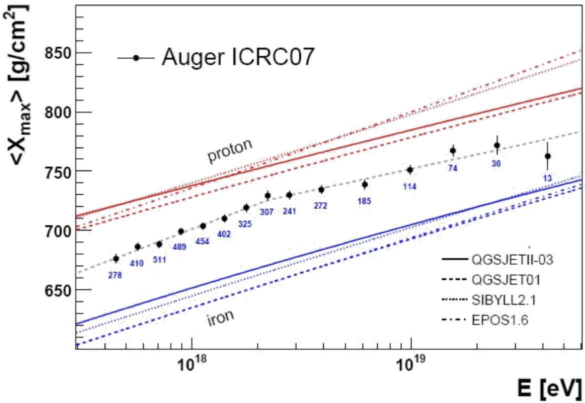

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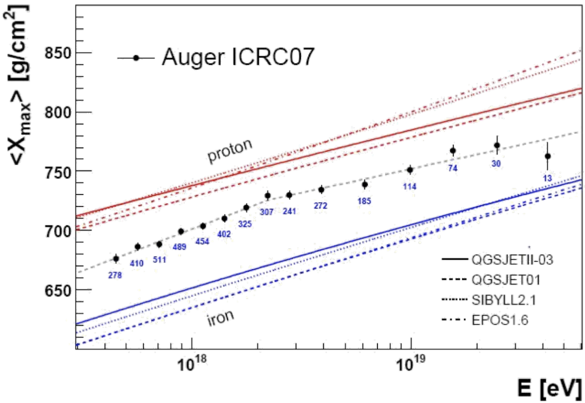

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Conclusion

The base design of the Southern Pierre Auger Observatory is complete

UHECR Spectrum shows a strong suppression above 4×10^{19} eV

Top-down models disfavoured: no photon or neutrino detected

UHECR astronomy is beginning with “AGN” correlation

First giant step towards understanding the UHECR mystery

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Thank you!!!