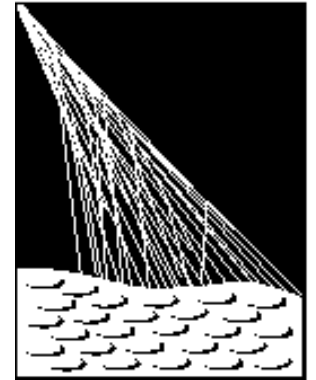


CEA

mercredi 26 novembre 2007

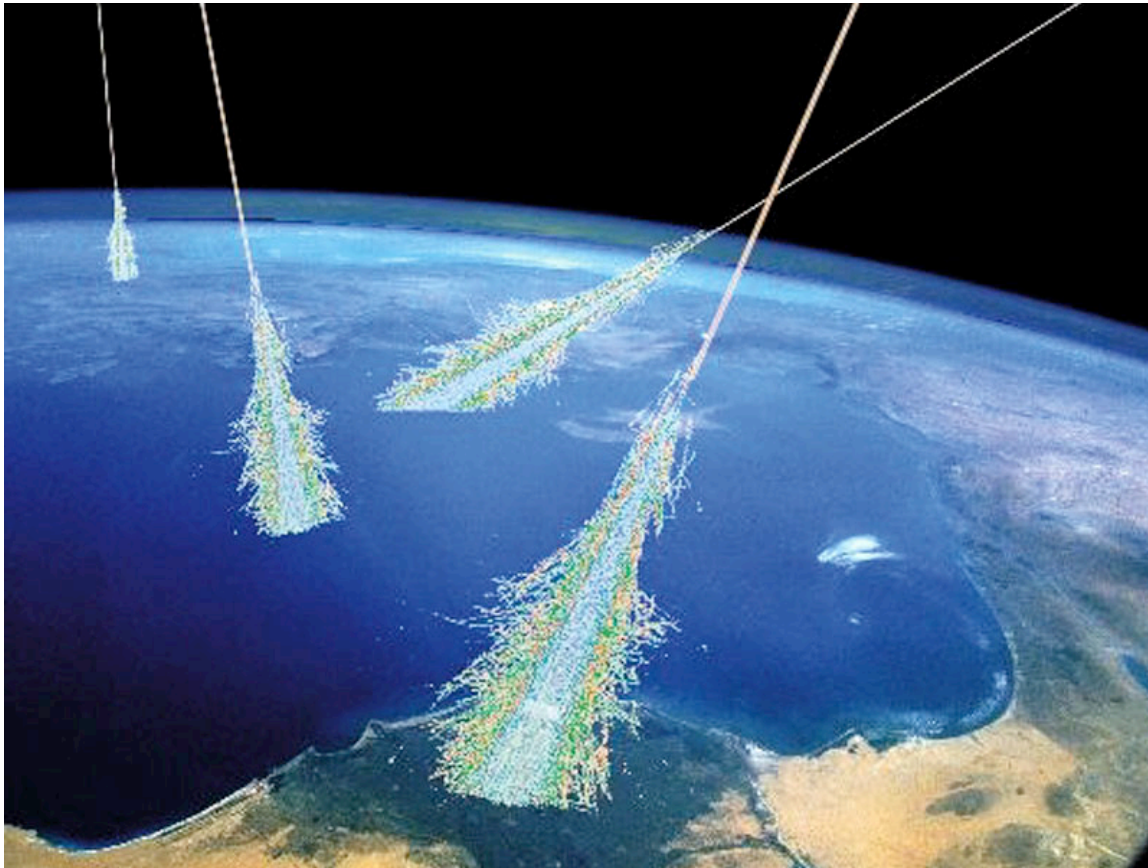


PIERRE
AUGER
OBSERVATORY

Latest news from the Pierre Auger Observatory

Cosmic Rays

Highly energetic particles that constantly fall on the Earth
(over 1000 cosmic rays went through my body since I started talking)

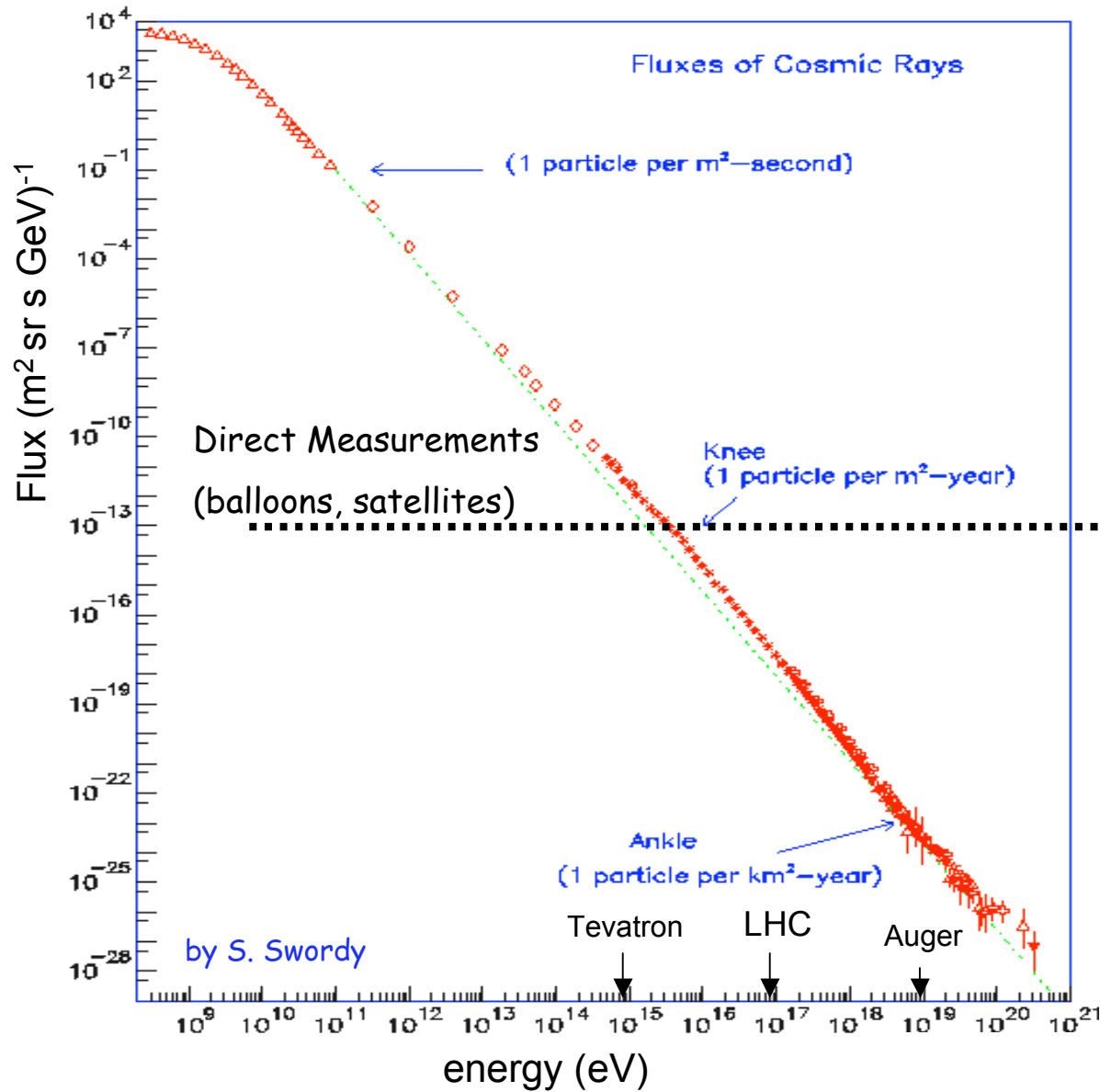


Credit: S. Swordy

- discovered in ~1910s
- mixture of nuclei at low energies
- composition is not known at higher energies
- sources are still not identified

Cosmic Rays

The "All Particle Spectrum"



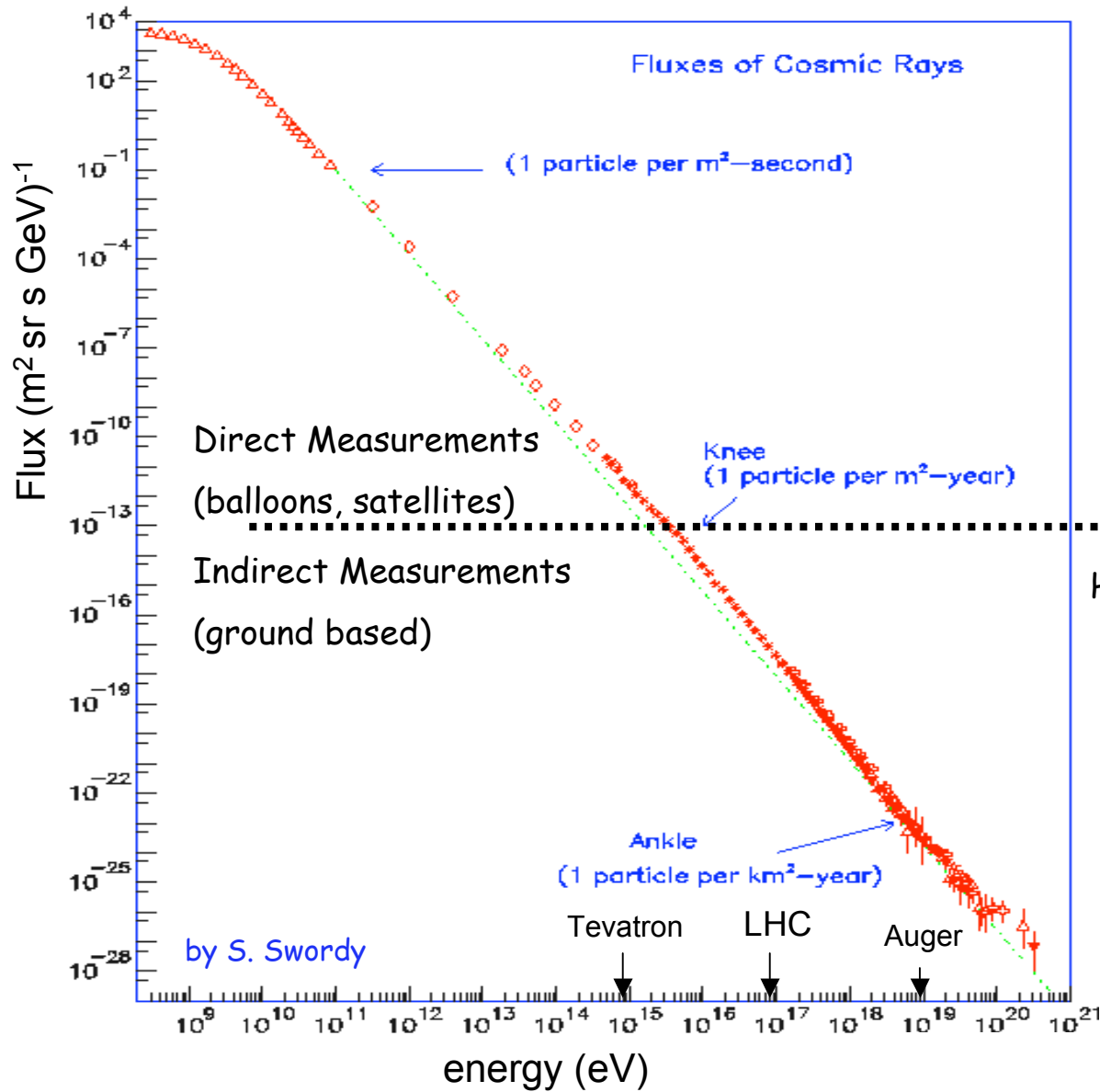
Regular power law $\sim E^{-3}$

Low Energies:

- direct measurements
- Composition: Nuclei
- origin: Galactic, SNR?

Cosmic Rays

The "All Particle Spectrum"



Regular power law $\sim E^{-3}$

Low Energies:

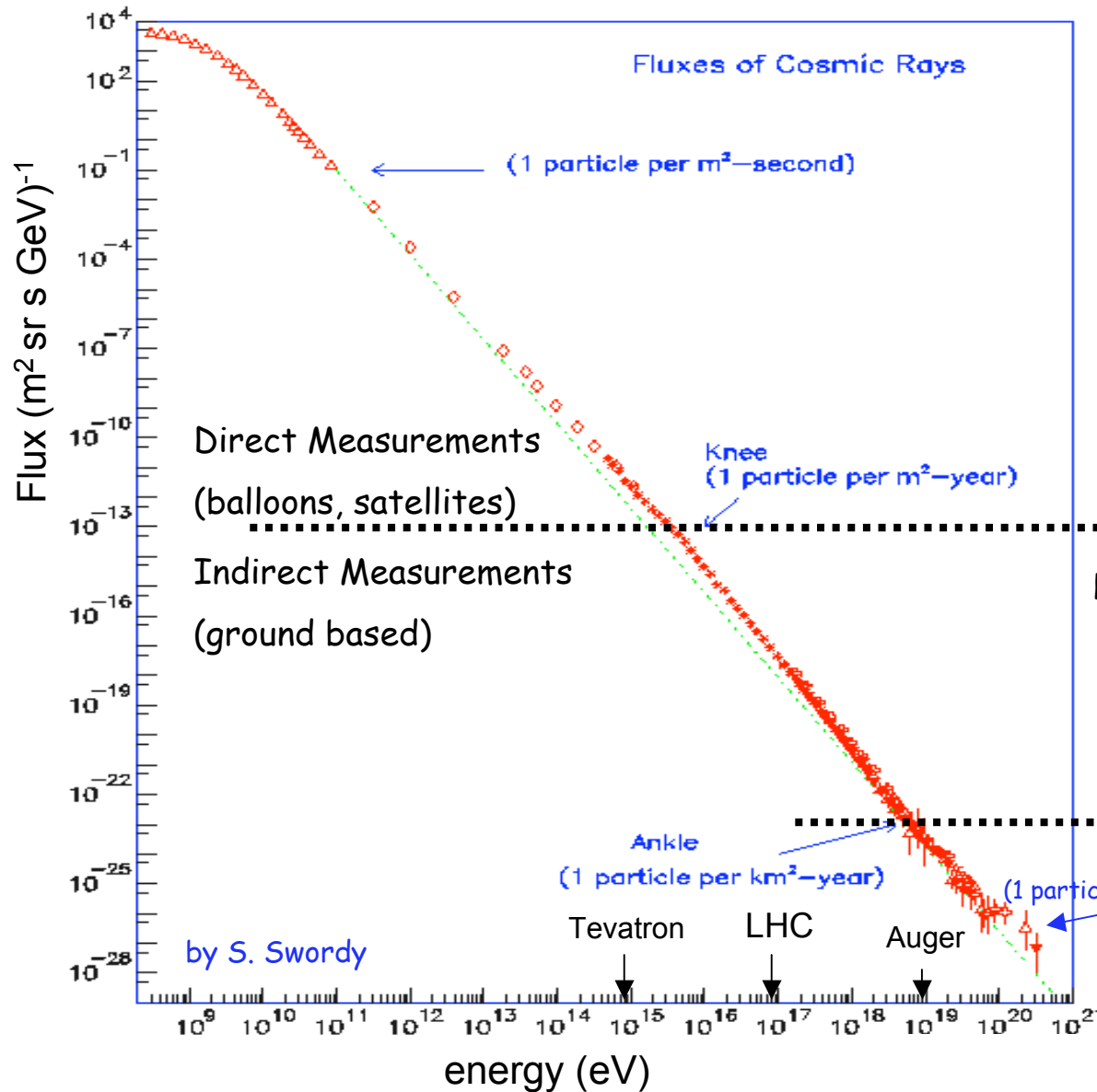
- direct measurements
- Composition: Nuclei
- origin: Galactic, SNR?

High Energy

- Composition?
- Sources?

Cosmic Rays

The "All Particle Spectrum"



Regular power law $\sim E^{-3}$

Low Energies:

- direct measurements
- Composition: Nuclei
- origin: Galactic, SNR?

High Energy

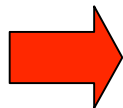
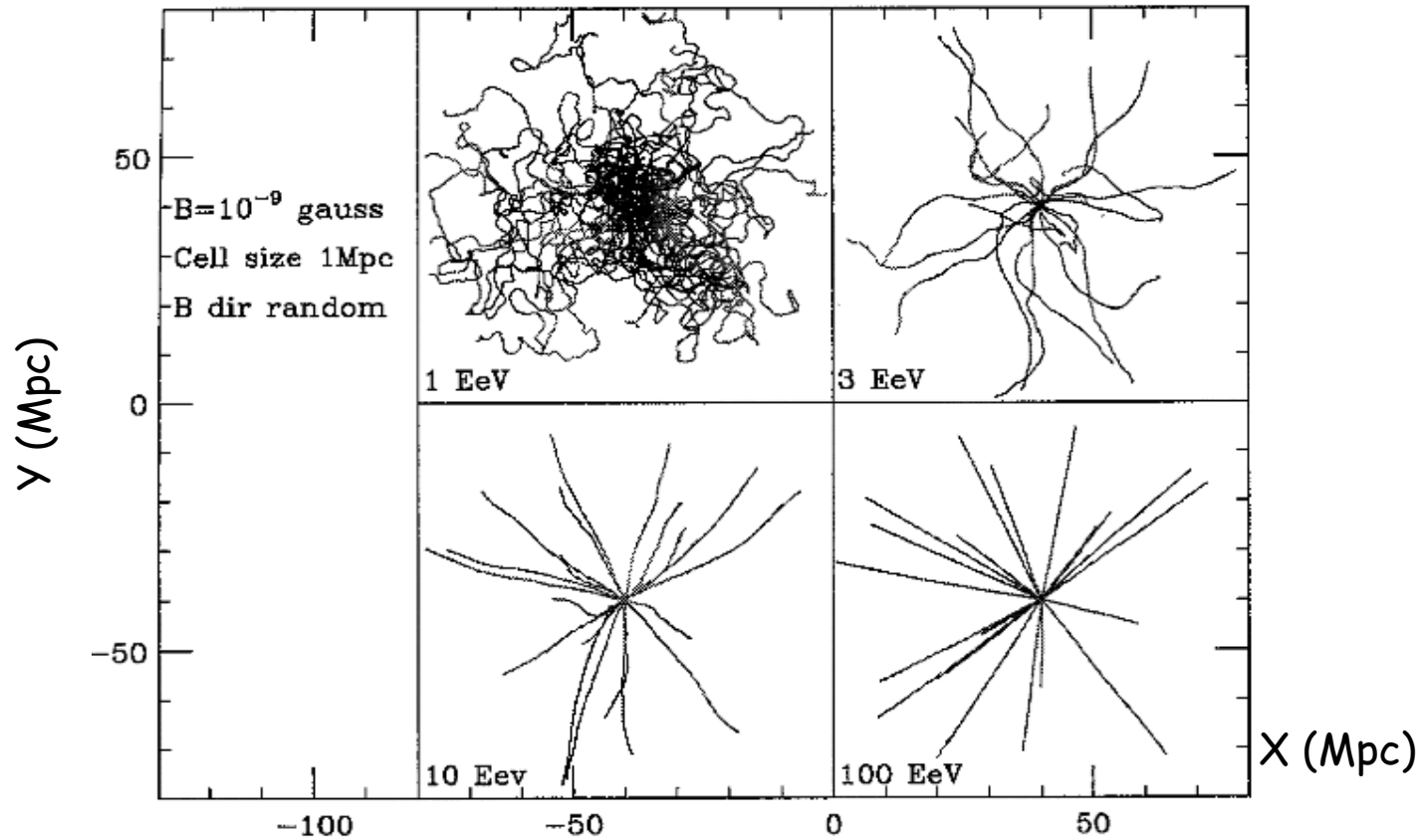
- Composition?
- Sources?

Ultra High Energy

- Composition?
- Sources?

Cosmic Rays: why high energy?

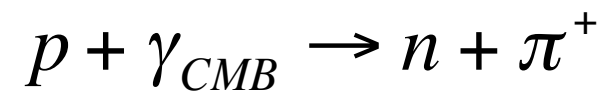
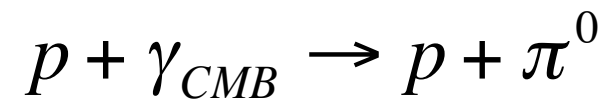
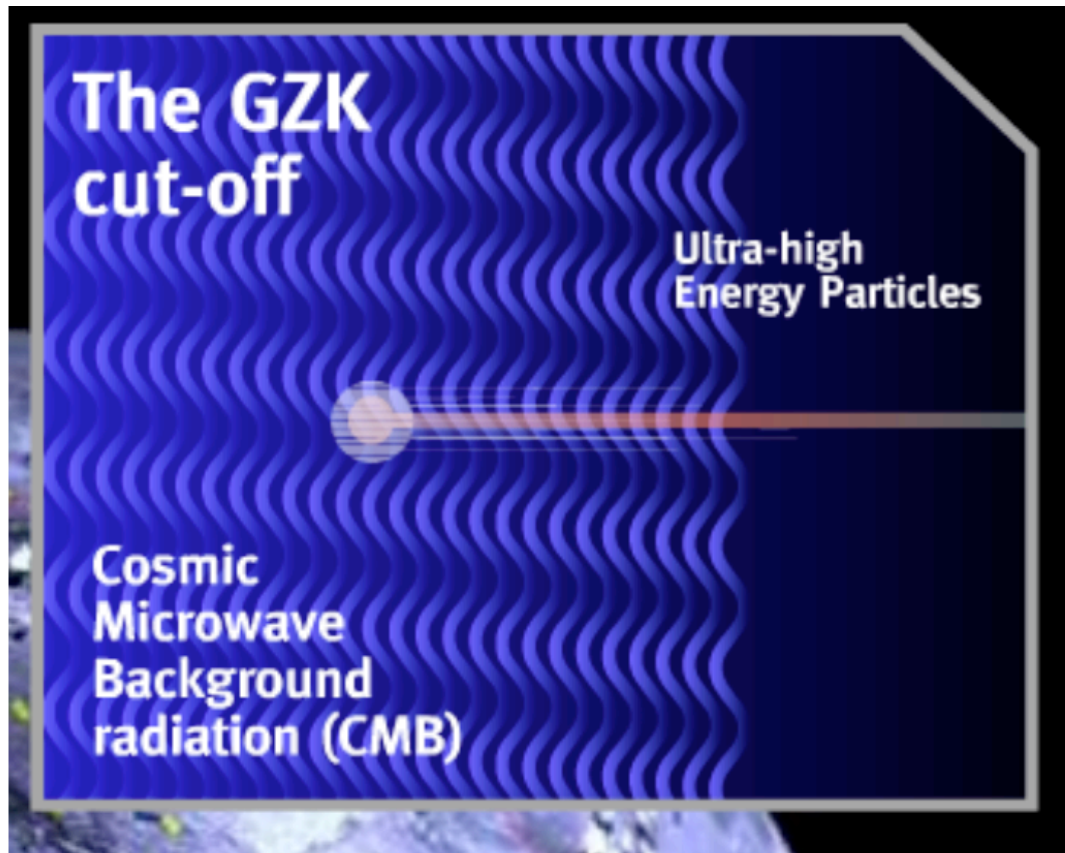
The magnetic rigidity increases with E



The trajectory is ballistic for $E > 10^{19}$ eV

Cosmic Rays: why high energy?

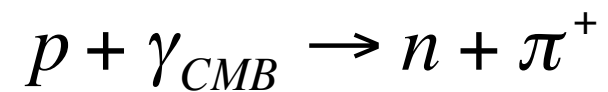
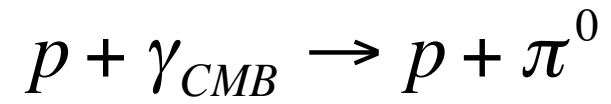
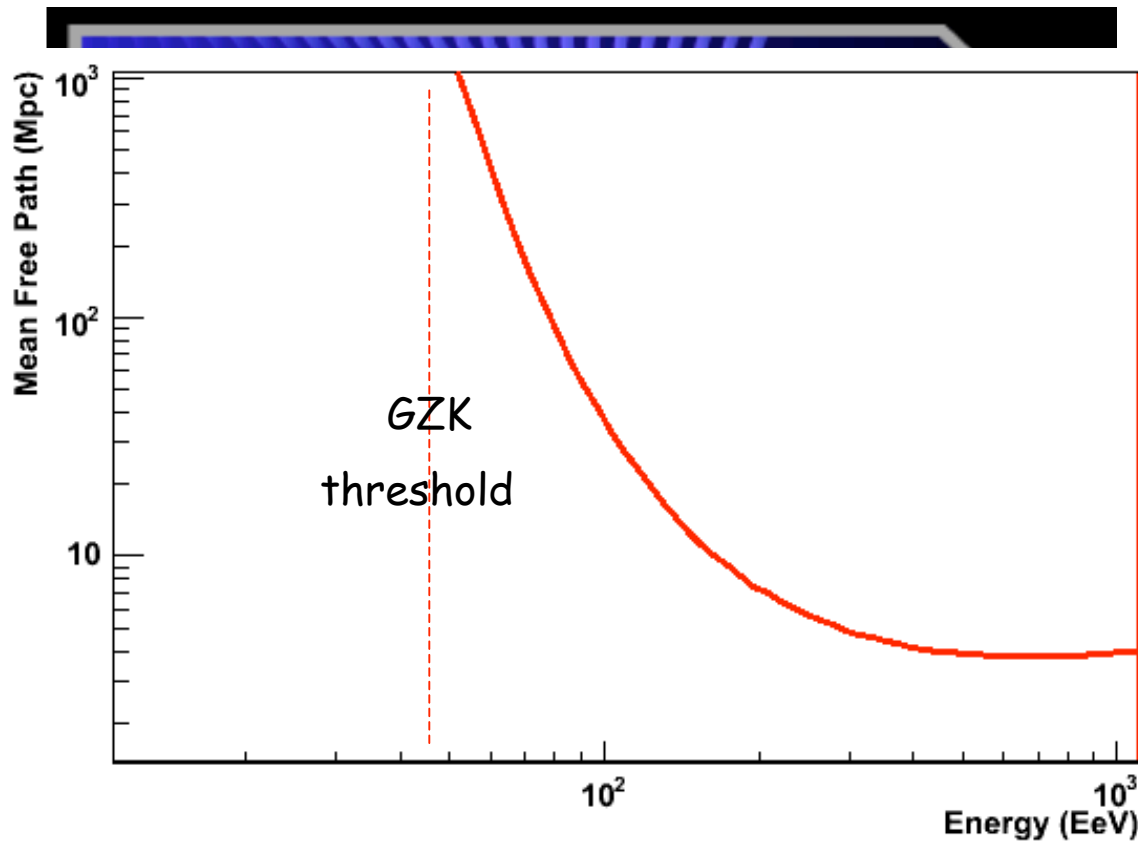
Greisen, Zatzepin & Kus'min (1966) - Interaction with the CMB background



$$E_{th} \sim 5 \times 10^{19} \text{ eV}$$

Cosmic Rays: why high energy?

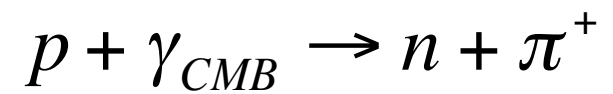
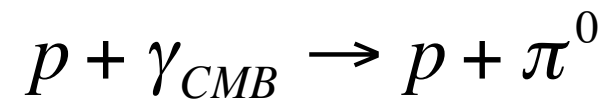
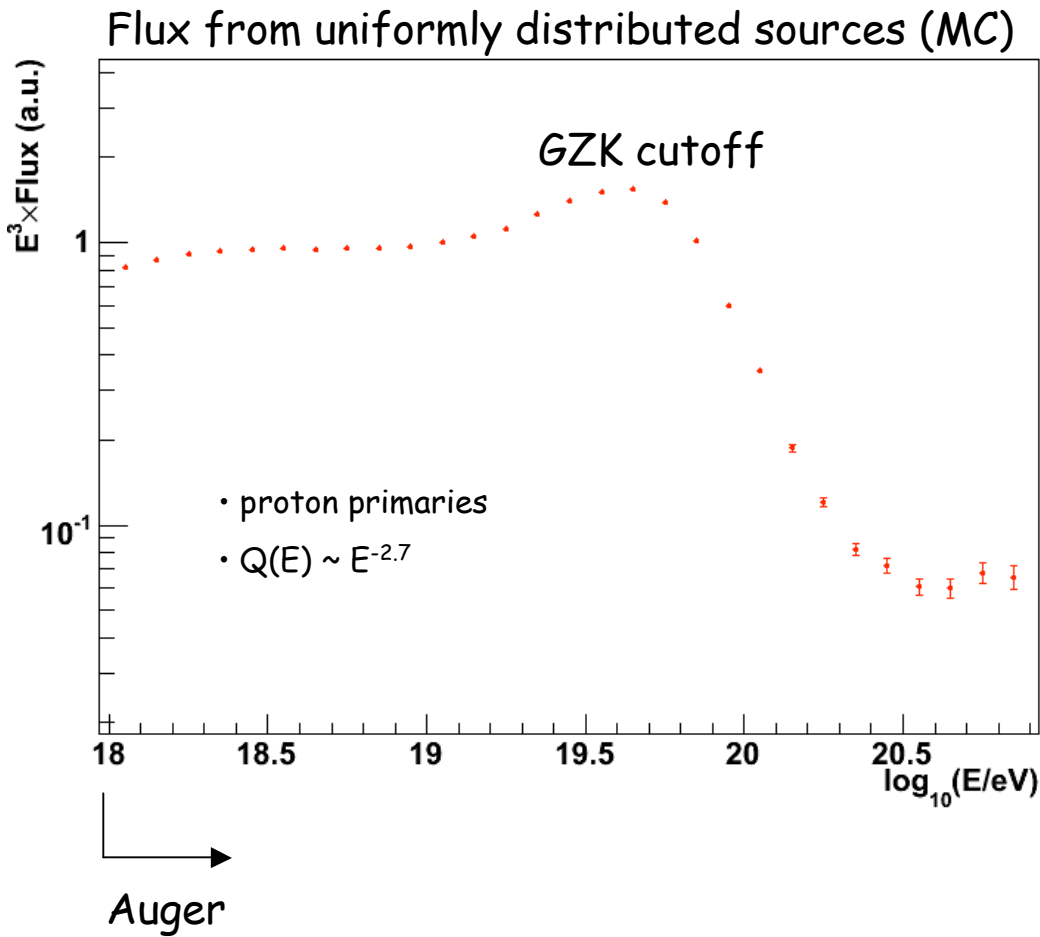
Greisen, Zatzepin & Kus'min (1966) - Interaction with the CMB background



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Cosmic Rays: why high energy?

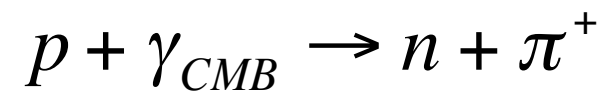
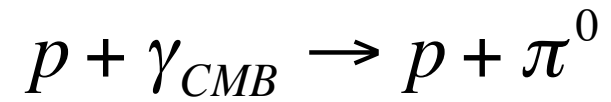
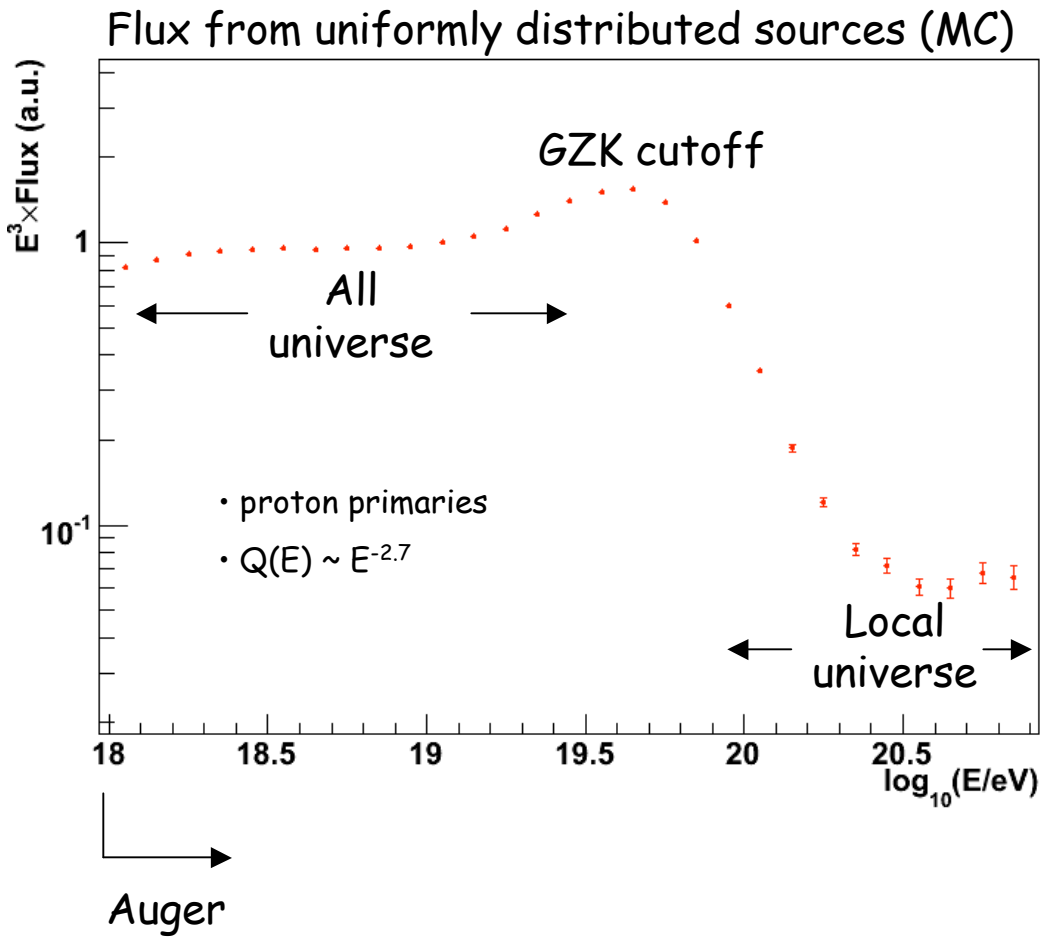
Interaction with the CMB background



$$E_{\text{th}} \sim 5 \times 10^{19} \text{ eV}$$

Cosmic Rays: why high energy?

Interaction with the CMB background

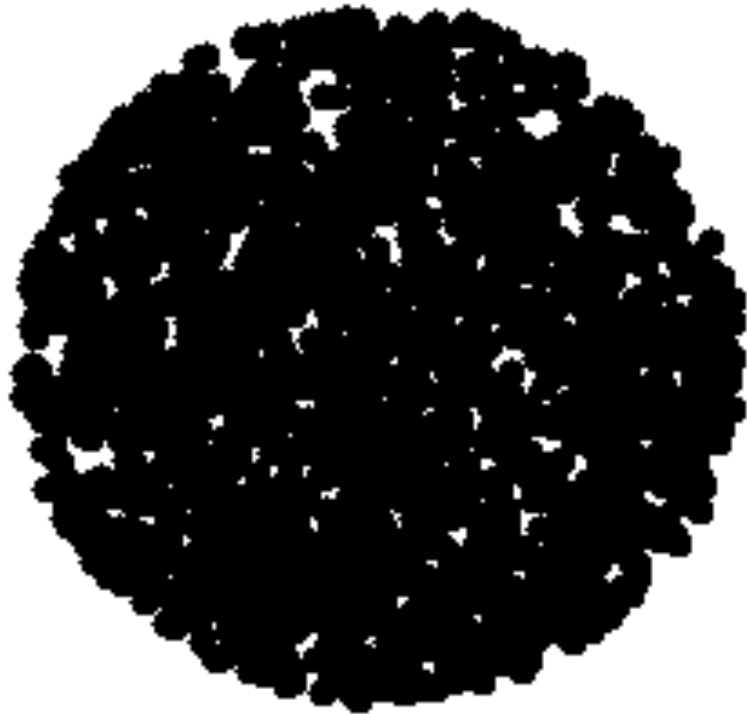


$$E_{th} \sim 5 \times 10^{19} \text{ eV}$$

GZK cutoff is NOT a sharp cutoff!!

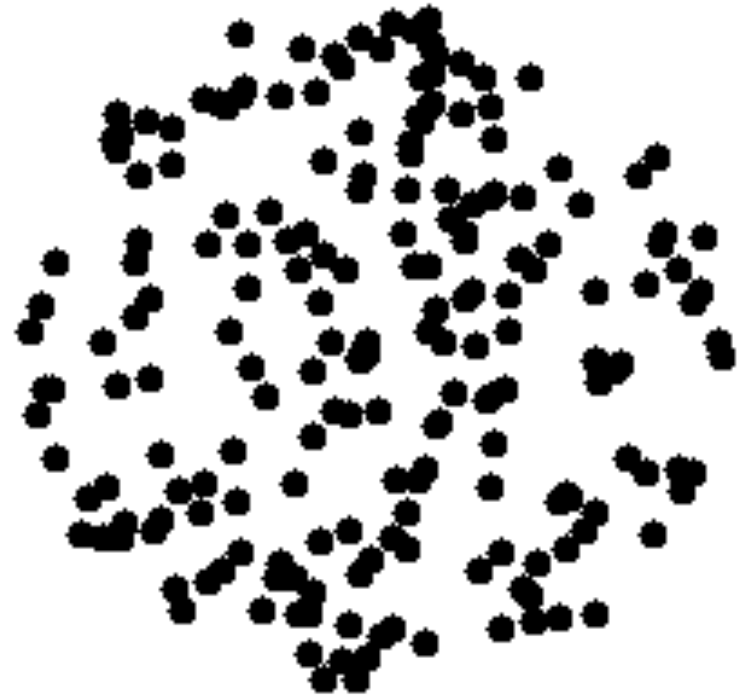
Cosmic Rays: why high energy?

Expected sky at 10^{19} eV



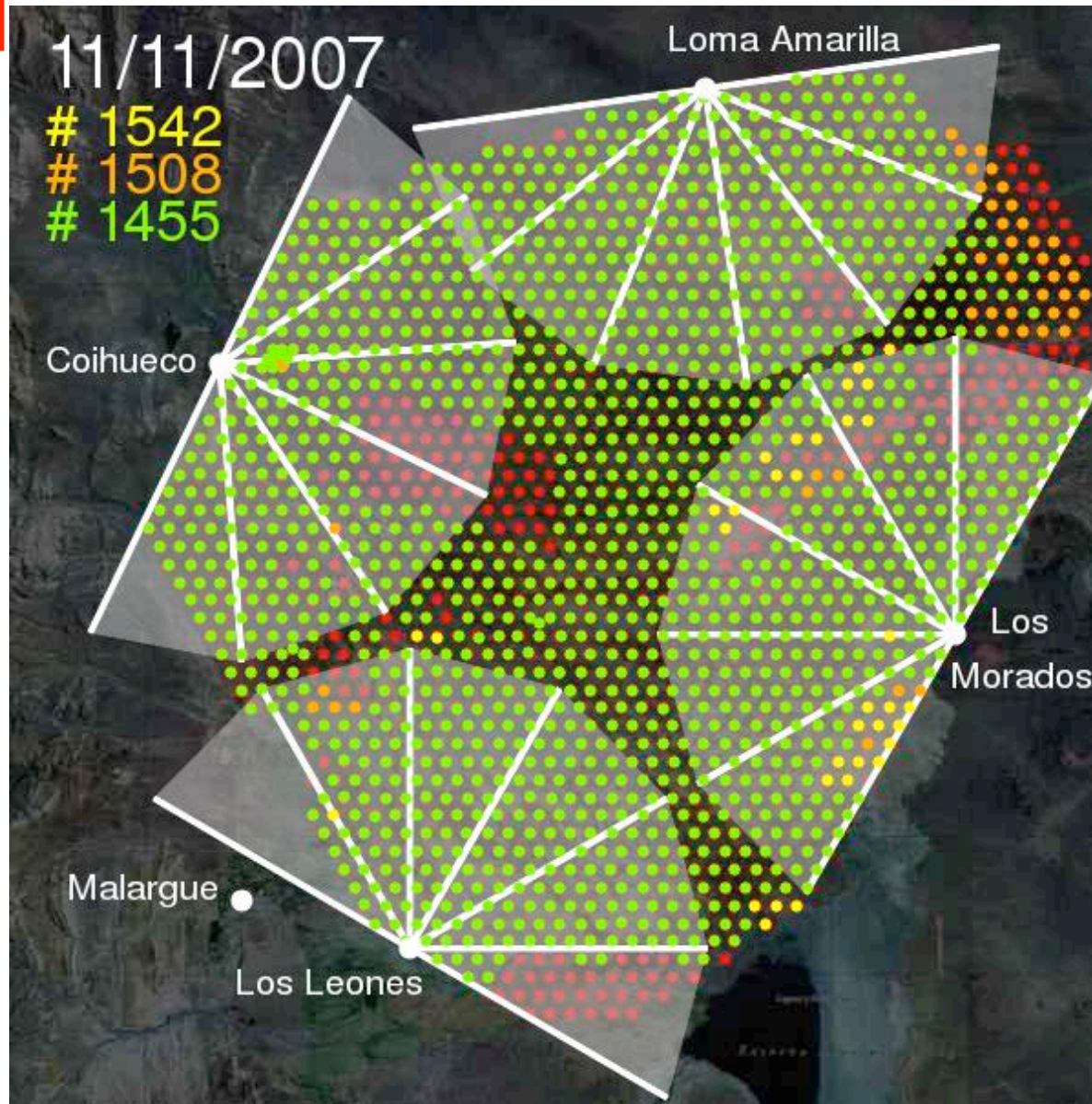
We observe the entire universe, still isotropic!!

Expected sky at 10^{20} eV



Sources can be discriminated

Southern Site: 3000 km² (10 fois Paris)



A surface detector
(SD):

- 1600 water Cherenkov detector
- ~100 % duty cycle
- large collecting area (3000 km²)

A fluorescence detector
(FD)

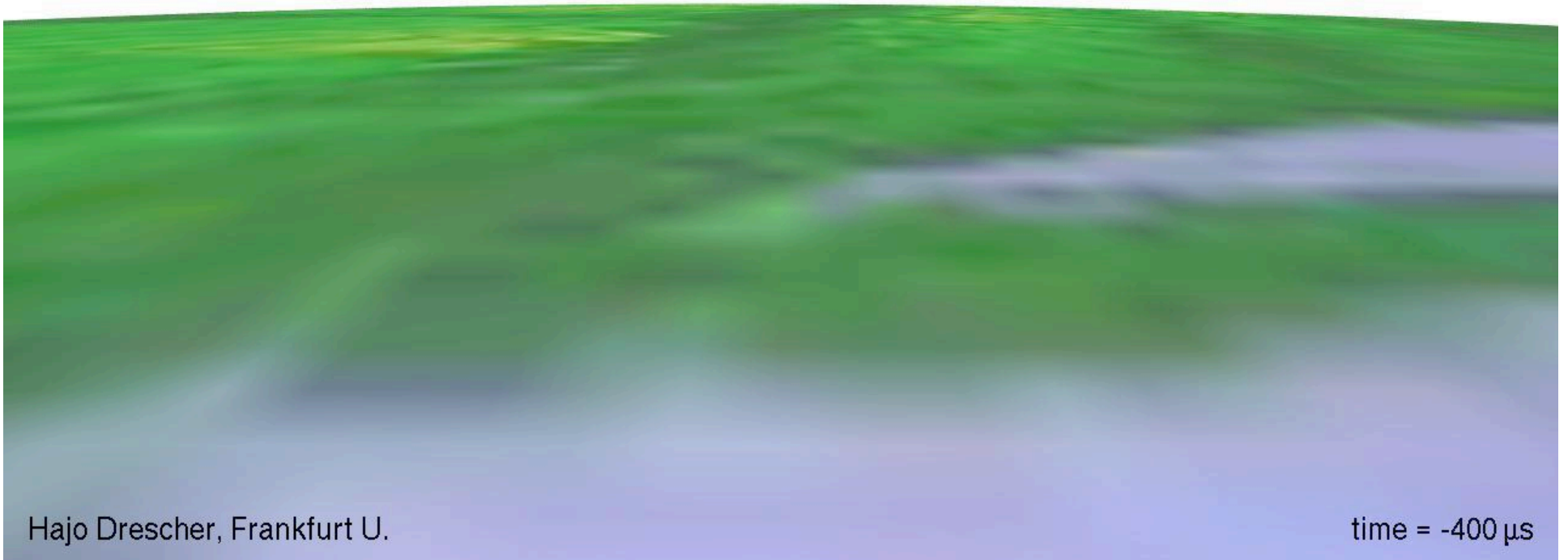
- 4 Eyes
- ~10% duty cycle (only moonless clear nights)

*Observatorio Pierre Auger
Av. San Martín Norte 304
Malargüe, (5613) Mendoza
Argentina*



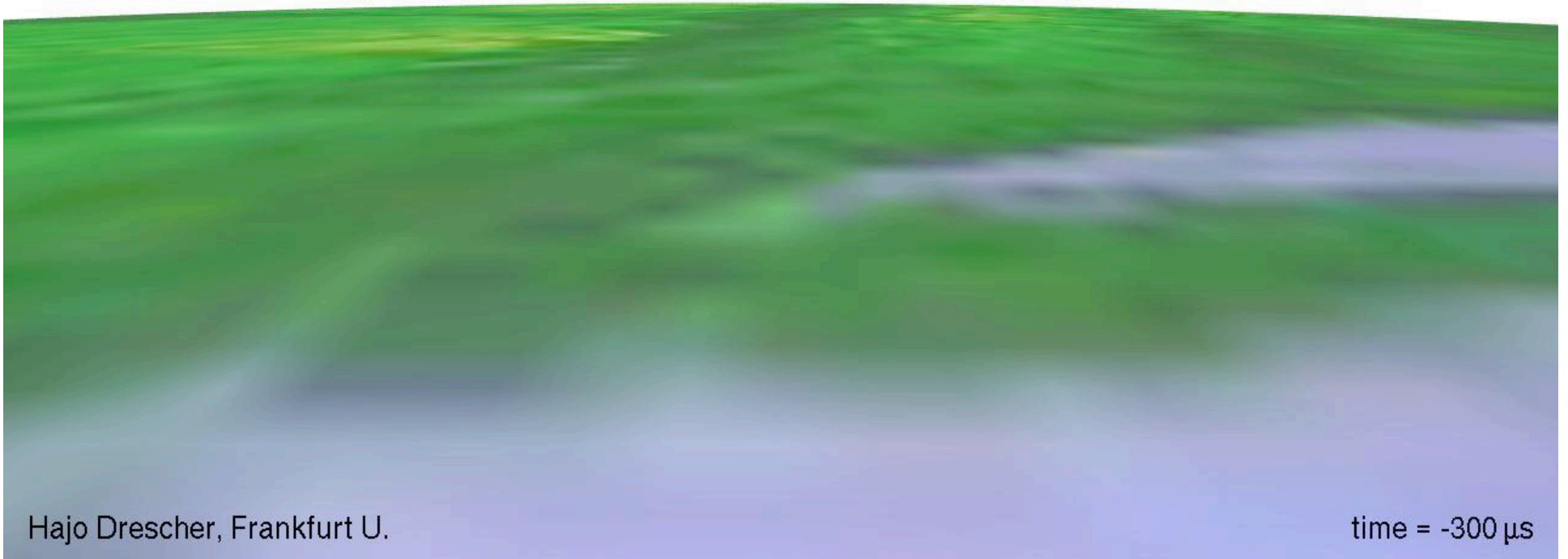
Hajo Drescher, Frankfurt U.

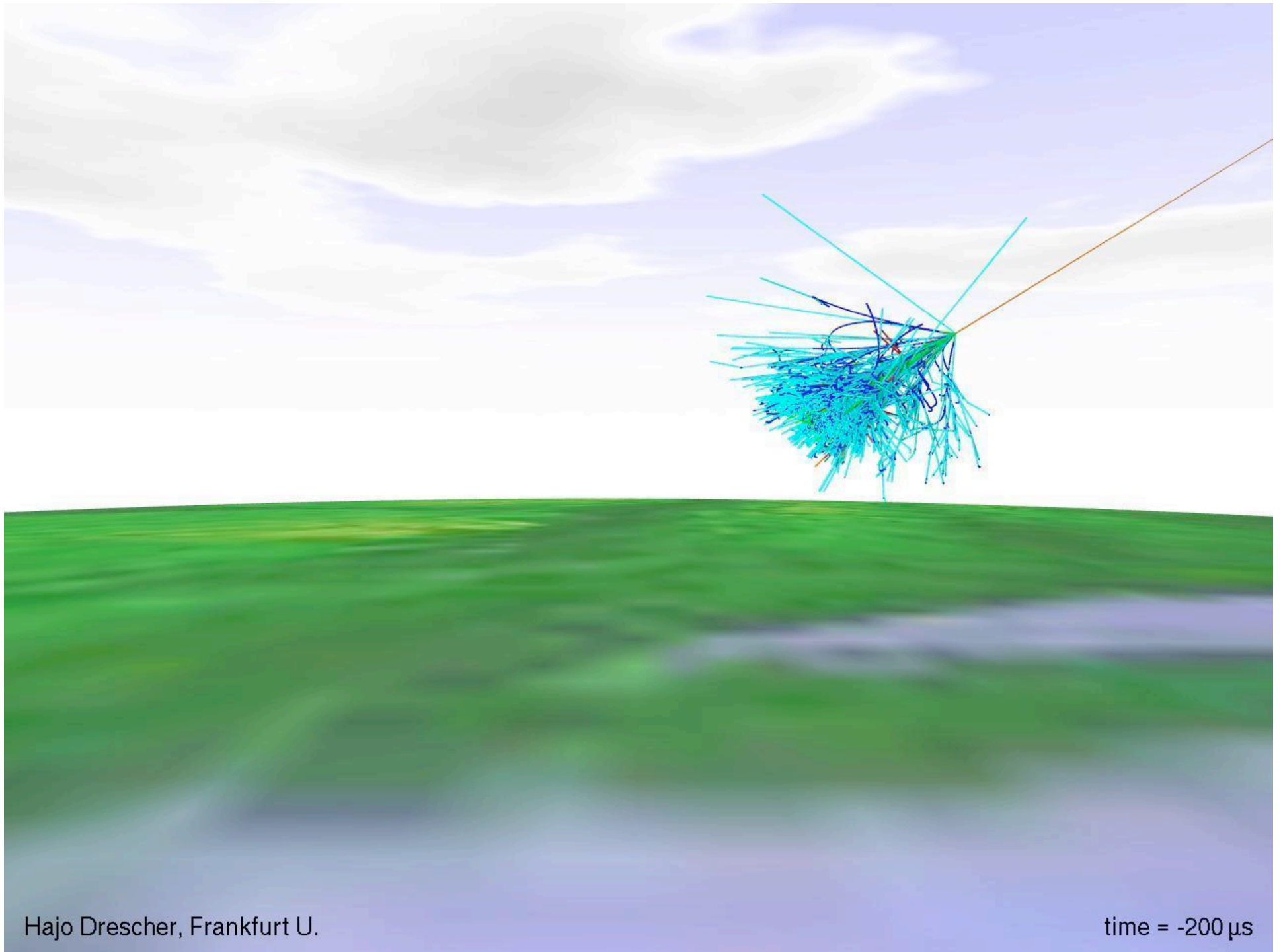
time = -1000 μ s



Hajo Drescher, Frankfurt U.

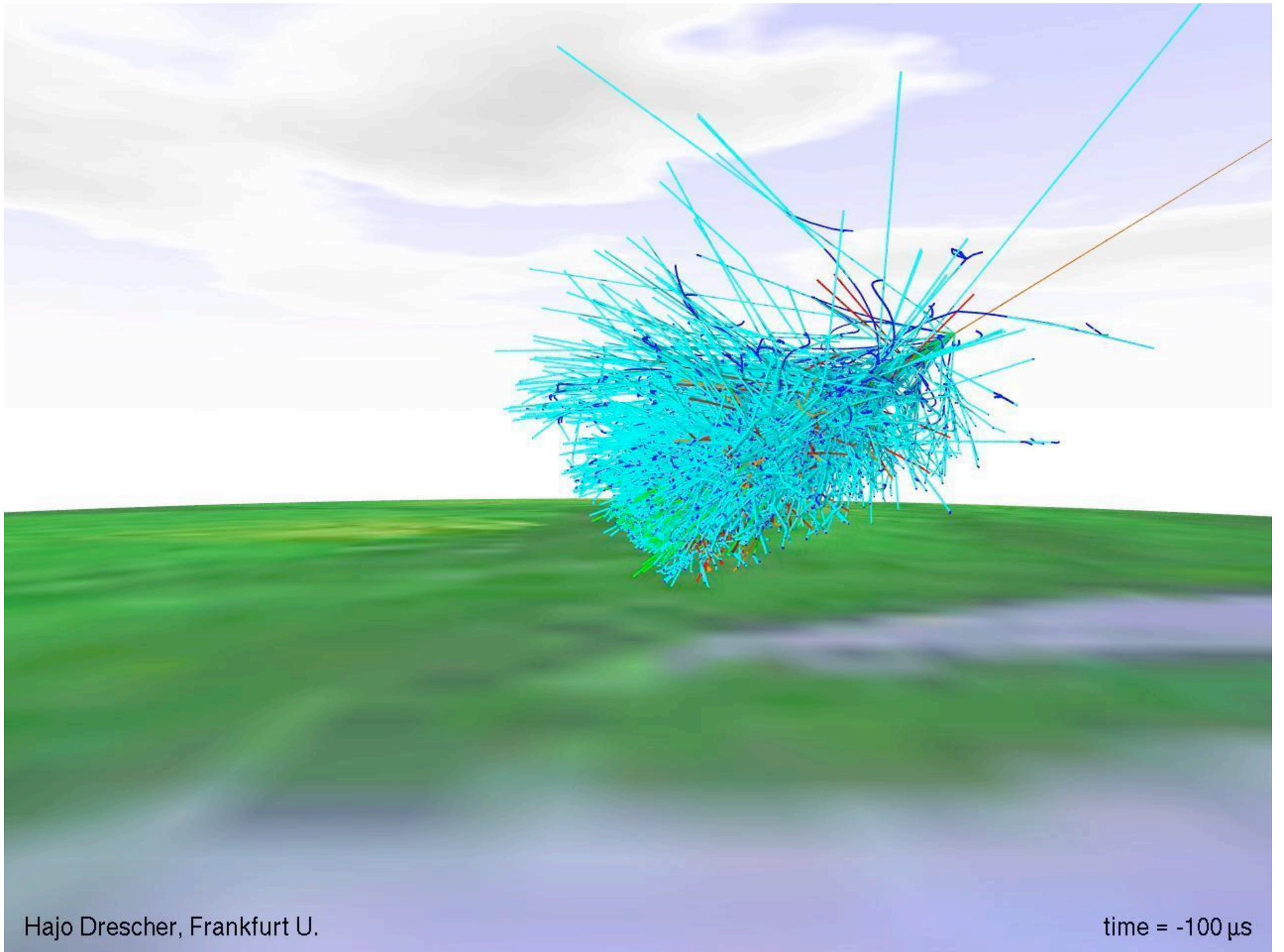
time = -400 μ s

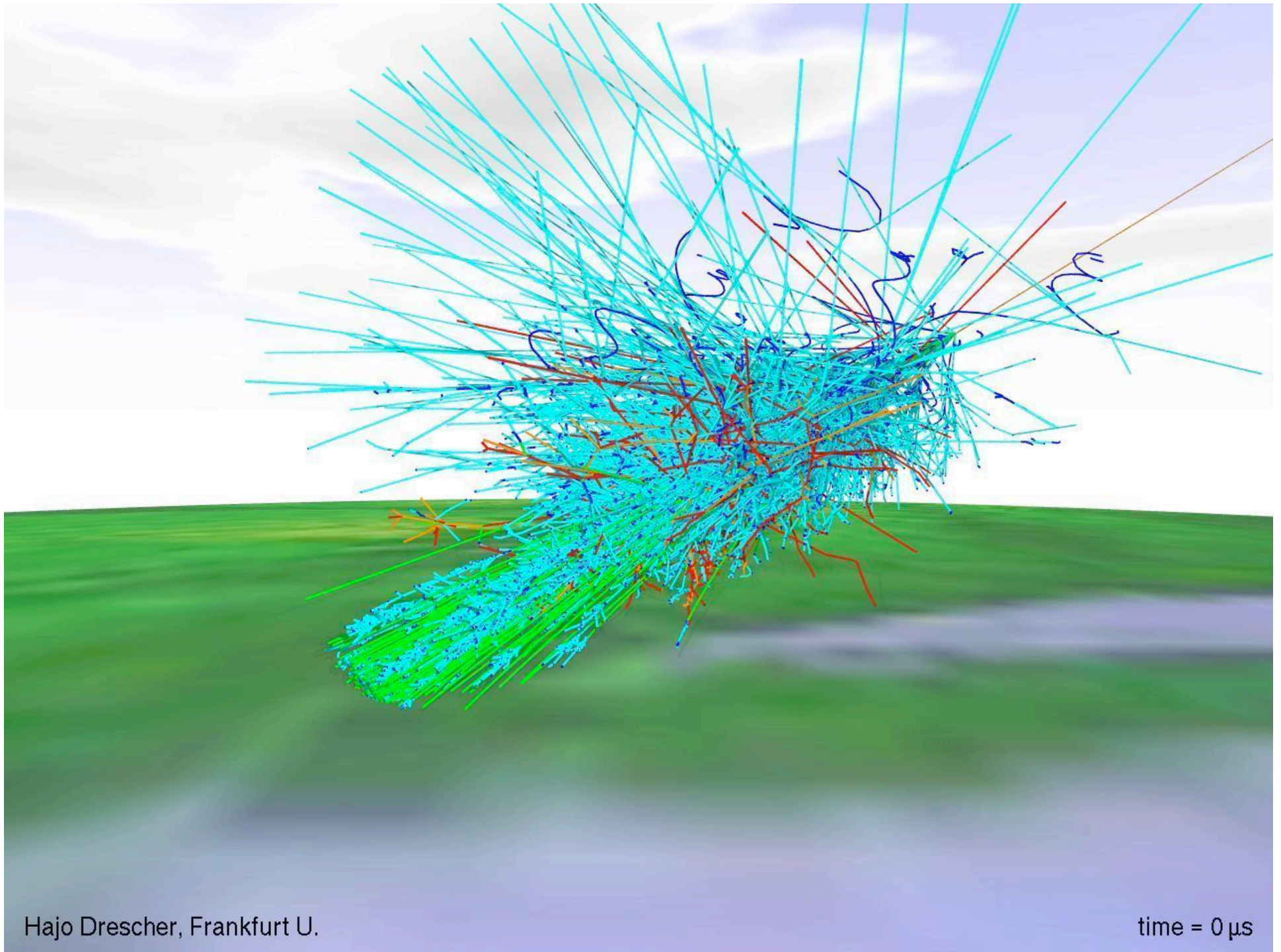


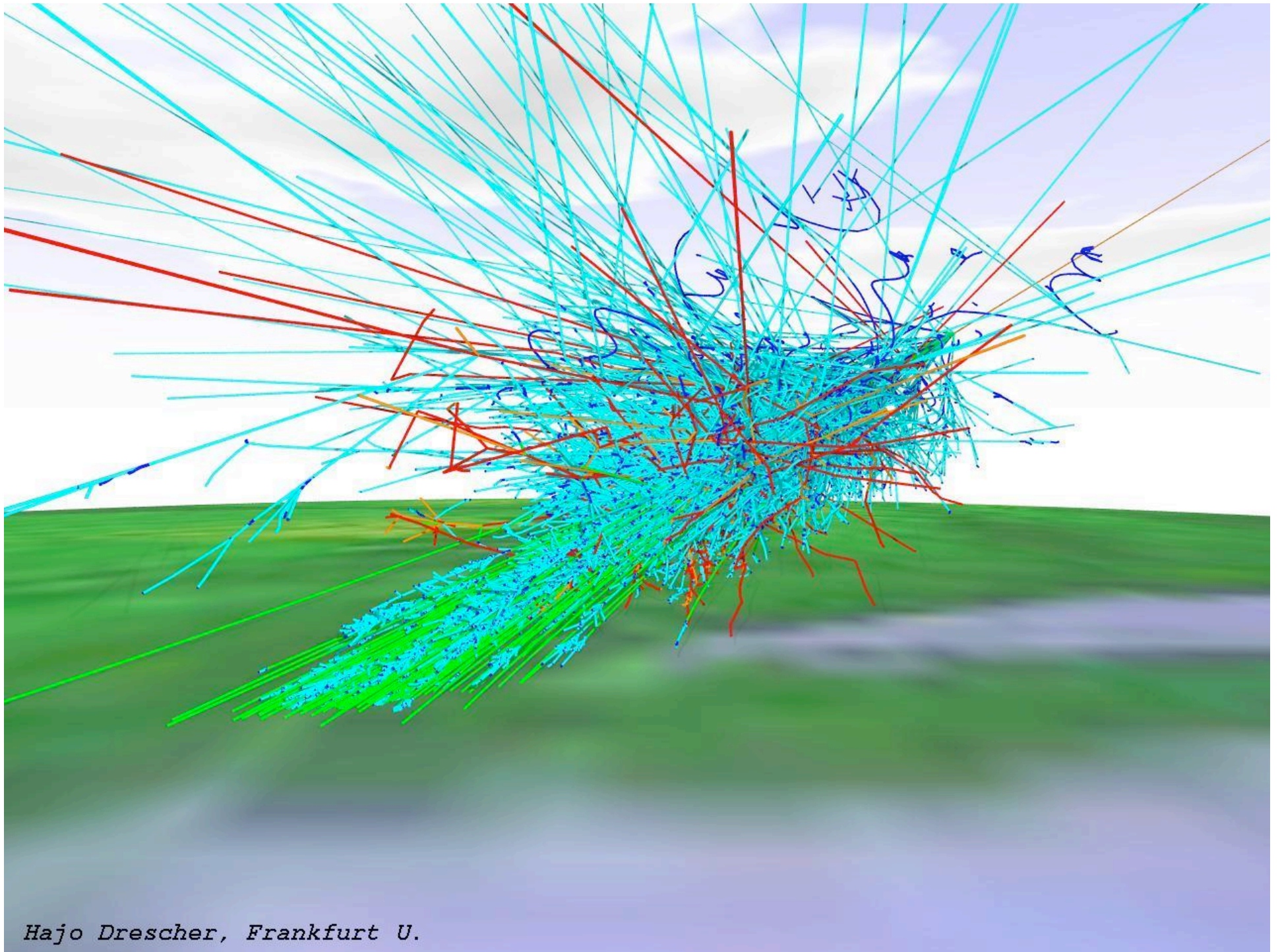


Hajo Drescher, Frankfurt U.

time = -200 μ s

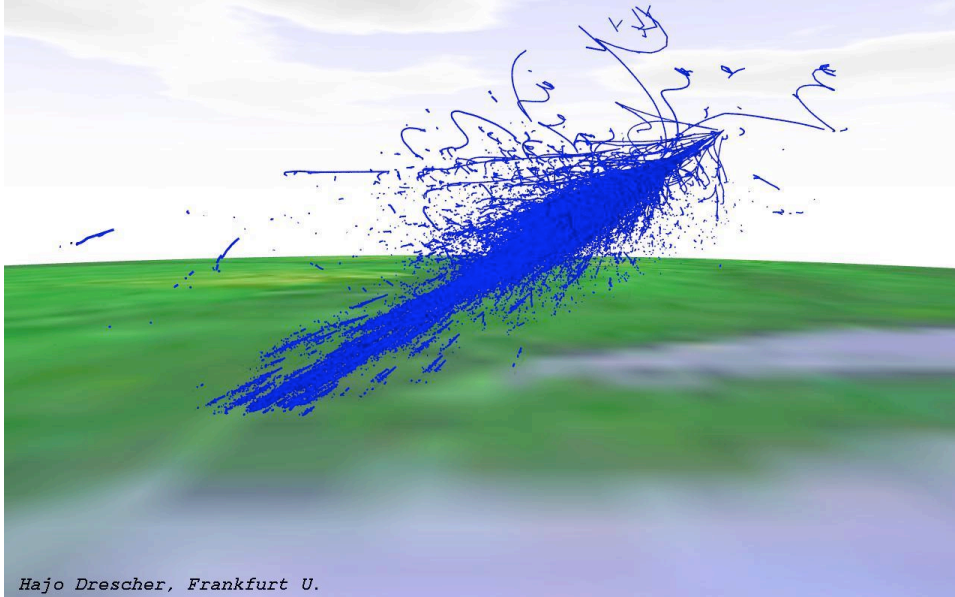




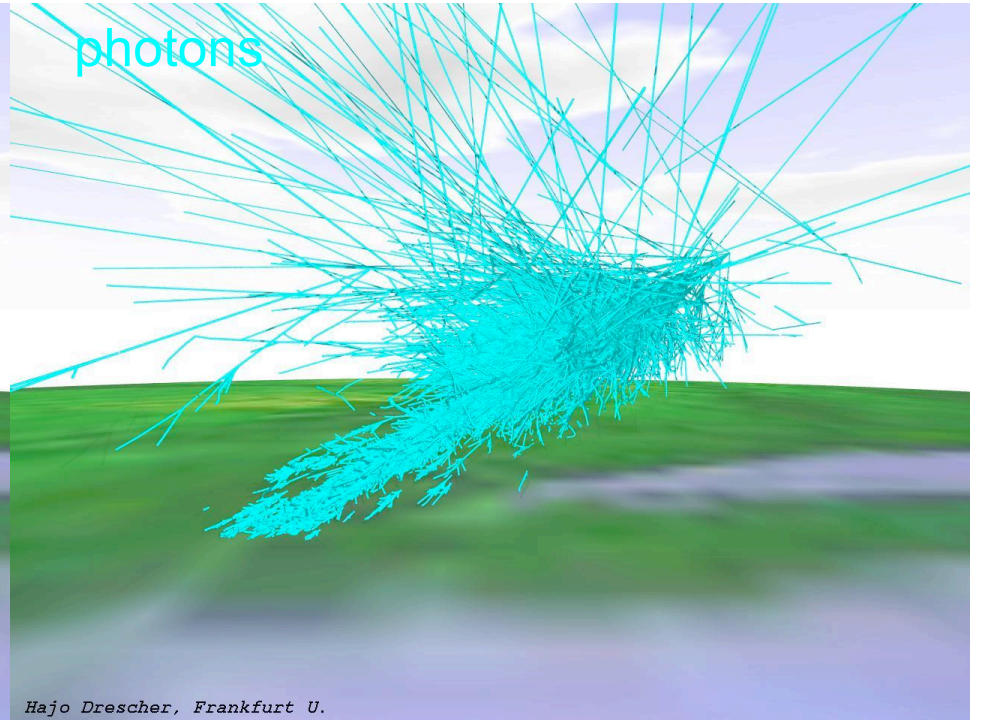


Hajo Drescher, Frankfurt U.

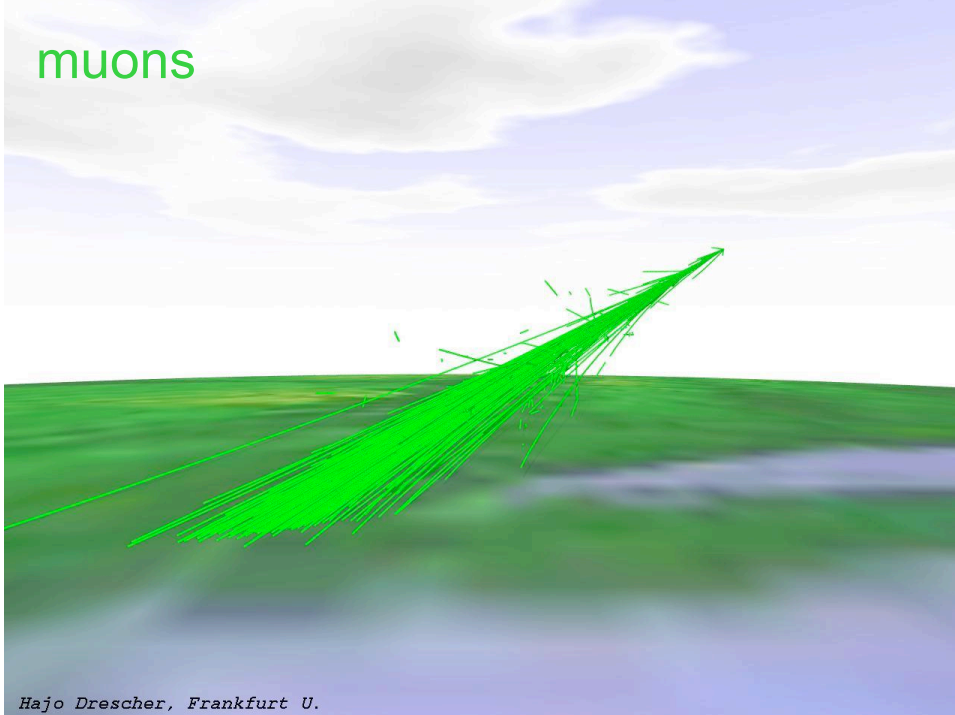
electrons/positrons



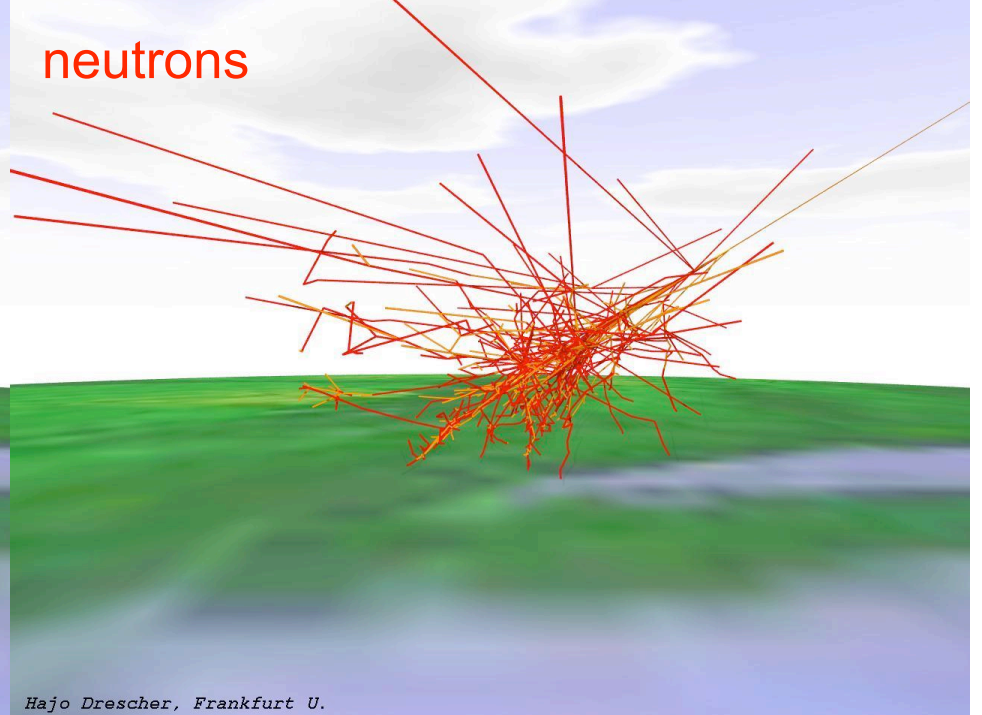
photons



muons



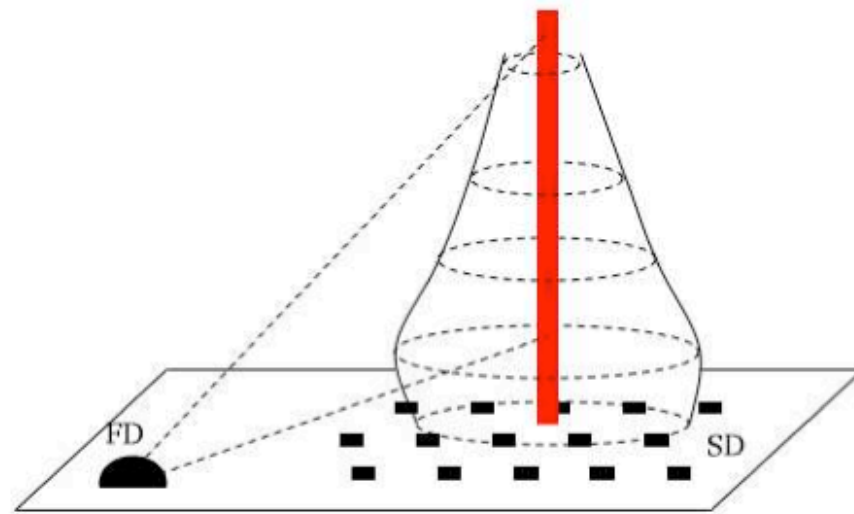
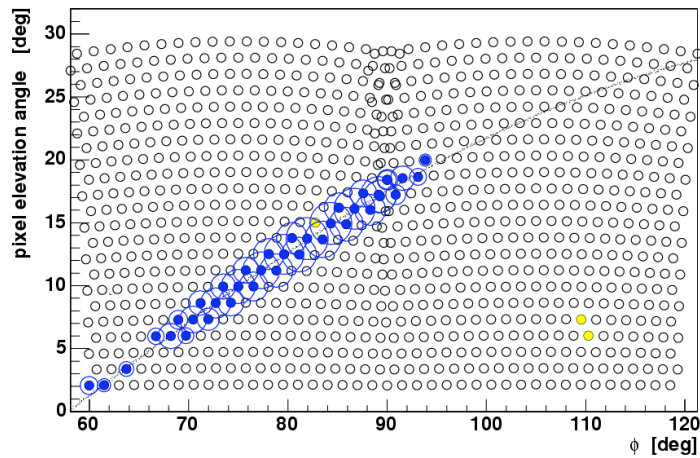
neutrons



Detection

SDP Id 931431 Run 452 Event 5431 Eye Id: 1

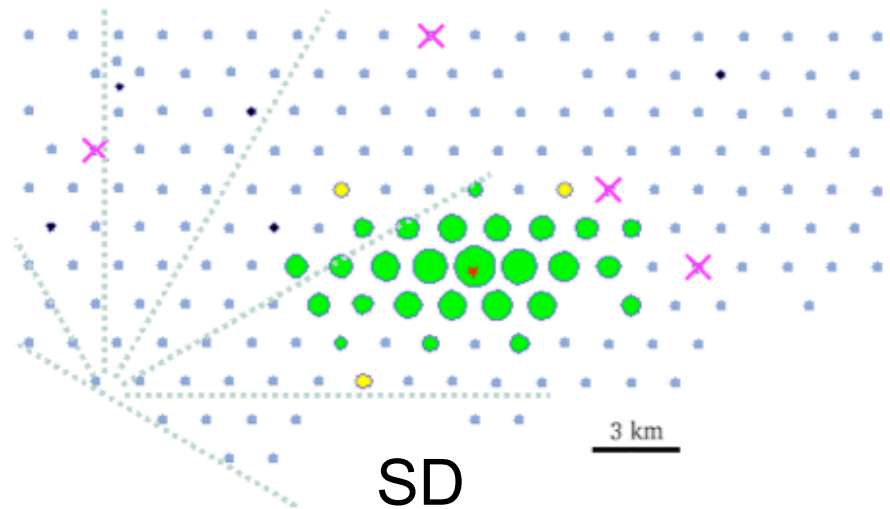
FD



fluorescence photons $\propto Y \frac{dE}{dX}$

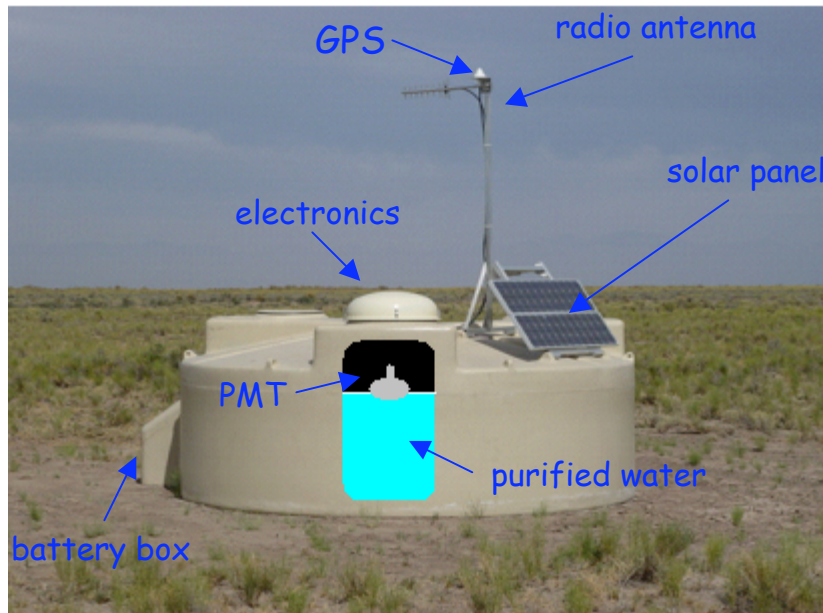
fluorescence yield

energy deposit



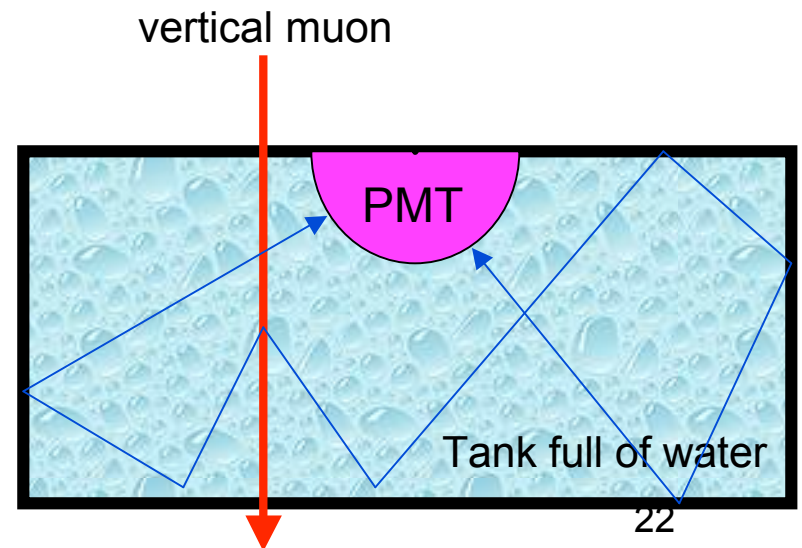
$$S = C_{em} \rho_{em} + C_{\mu} \rho_{muons} \quad 21$$

Detection: a local station



A tank is a *stand alone self calibrating* unit (can't wire 3000 km²)

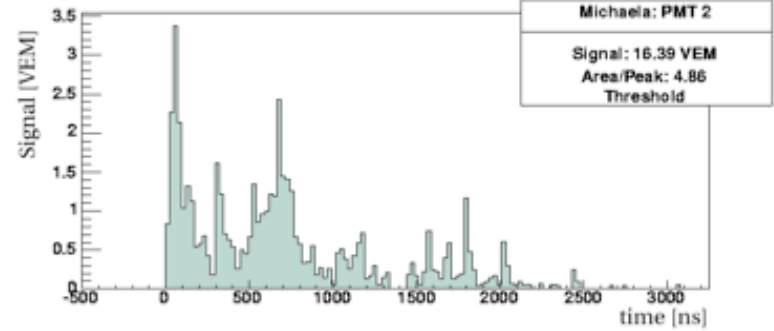
Unit of signal = VEM
= signal of a *vertical* muon



Event Reconstruction: SD

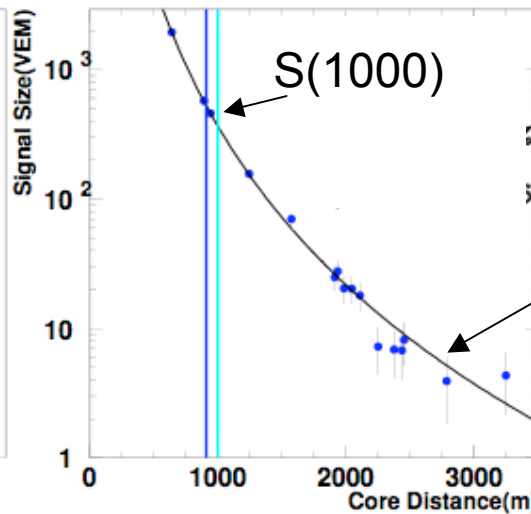
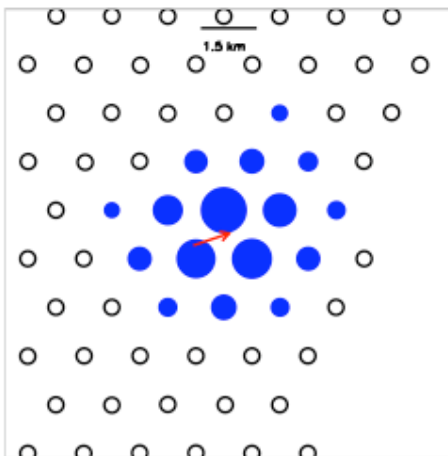
Direction from timing

θ



$$t_0 \quad \text{---} \quad d \quad \text{---} \quad t_0 + d/c \sin(\theta) \quad \text{---} \quad d \quad \text{---} \quad t_0 + 2d/c \sin(\theta)$$

$S(1000)$ from signal sizes

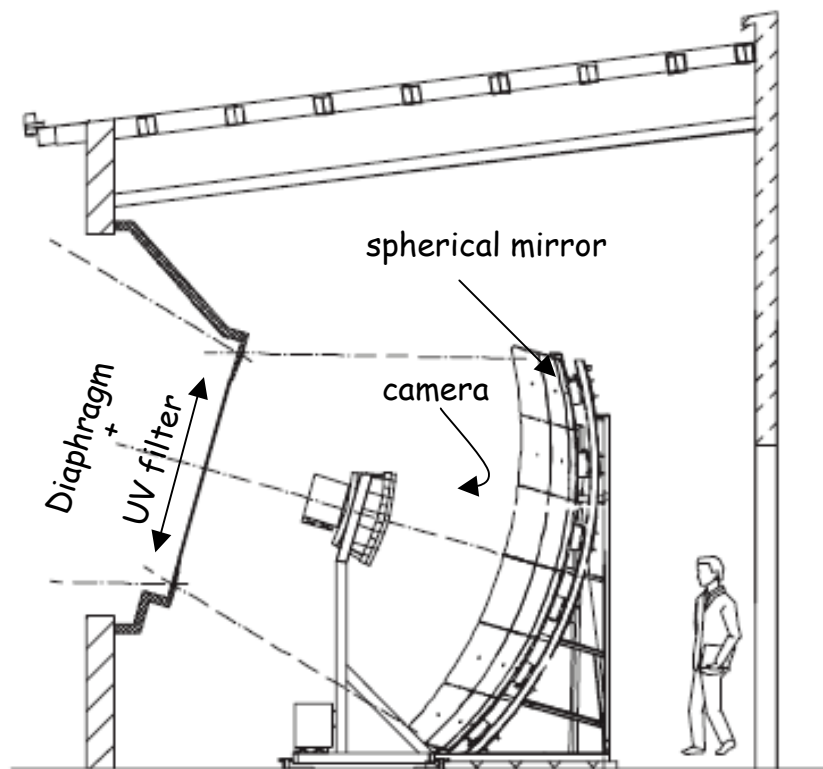


Lateral distribution function

The FD

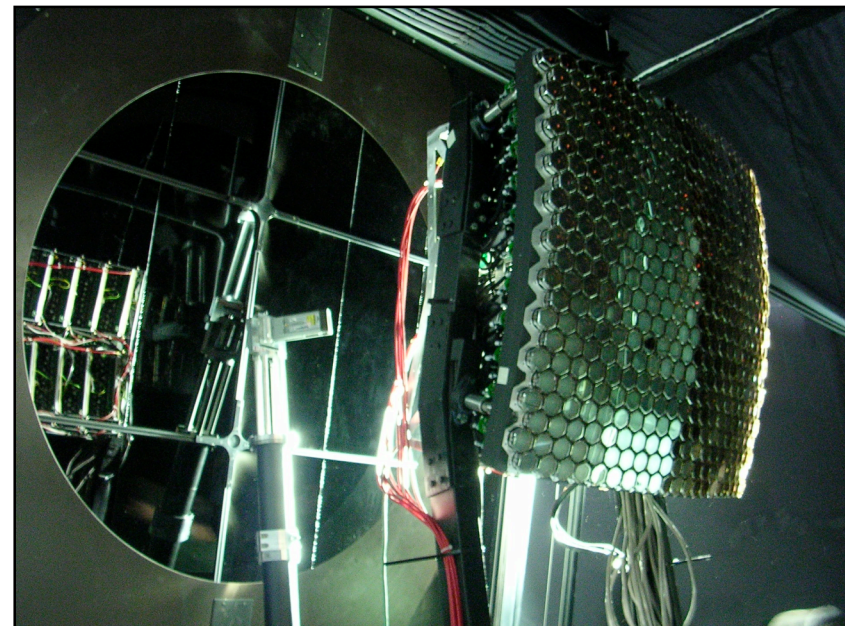
4 buildings with 6 telescopes each

Sketch of a fluorescence telescope:



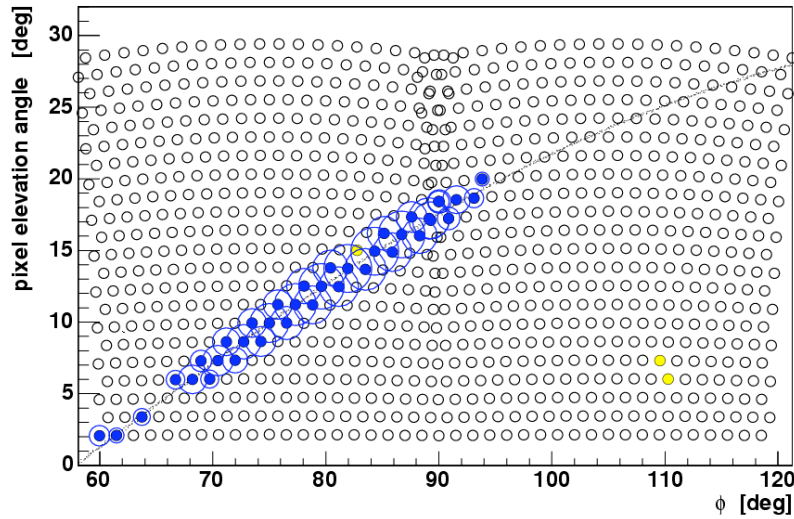
The camera:

- 440 pmt (1.5deg each)
- 100 ns FADC

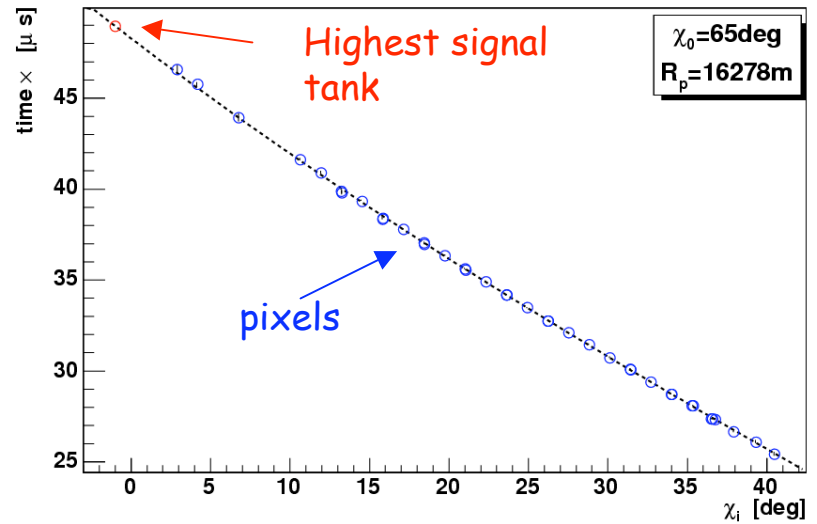


Event Reconstruction: FD

SDP Id 931431 Run 452 Event 5431 Eye Id: 1

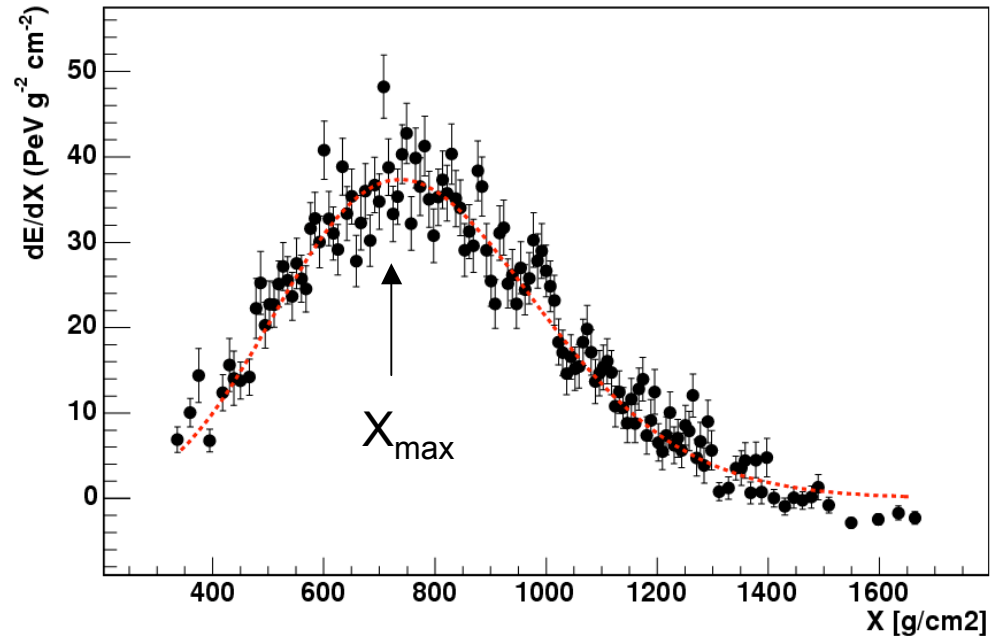


TimeFit Id 931431 Run 452 Event 5431 Eye Id: 1



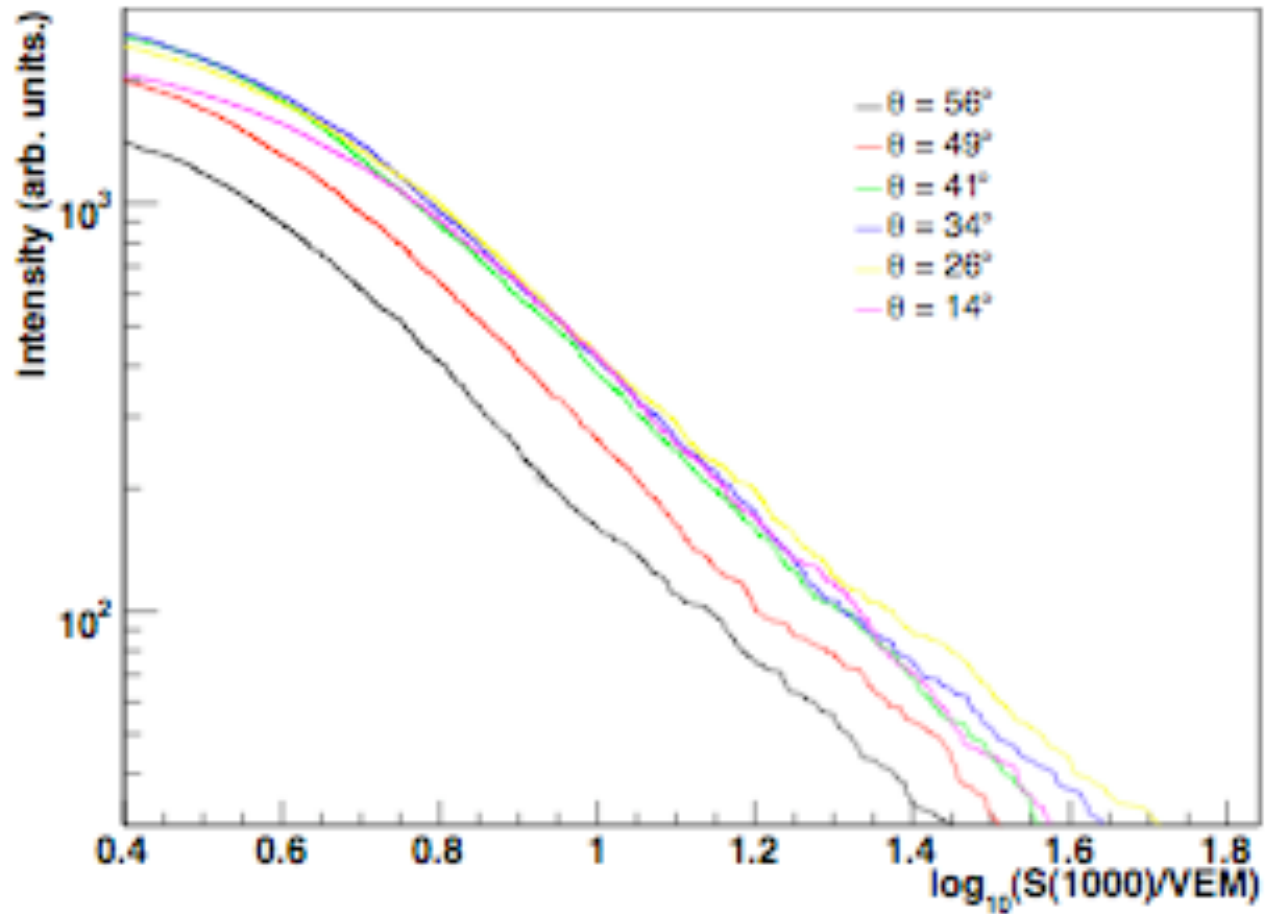
$$\text{photons} = G \cdot Y \cdot dE/dX$$

$$E = \int dX \frac{dE}{dX}$$

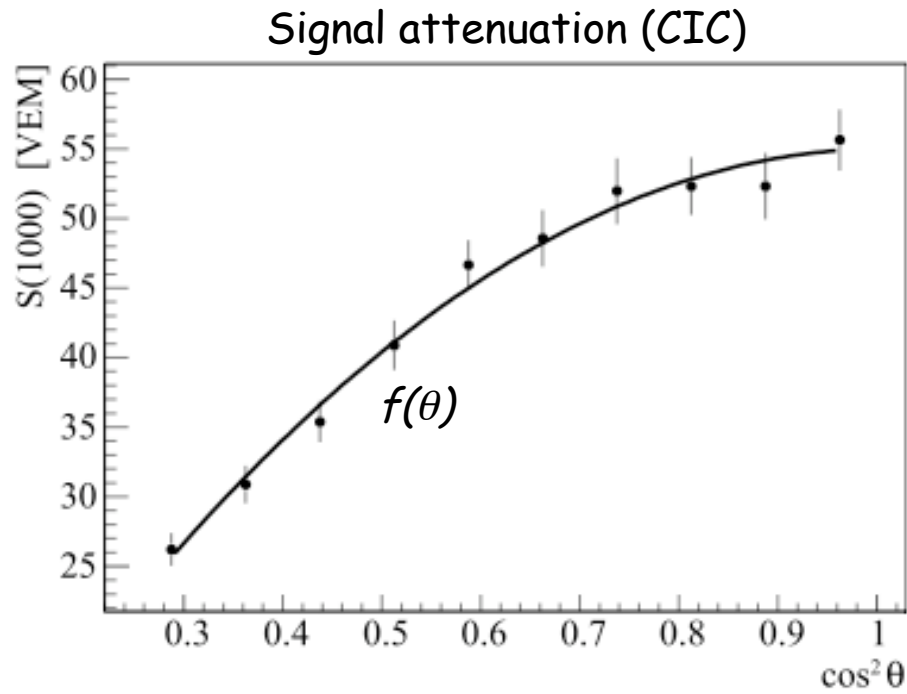


Energy Calibration

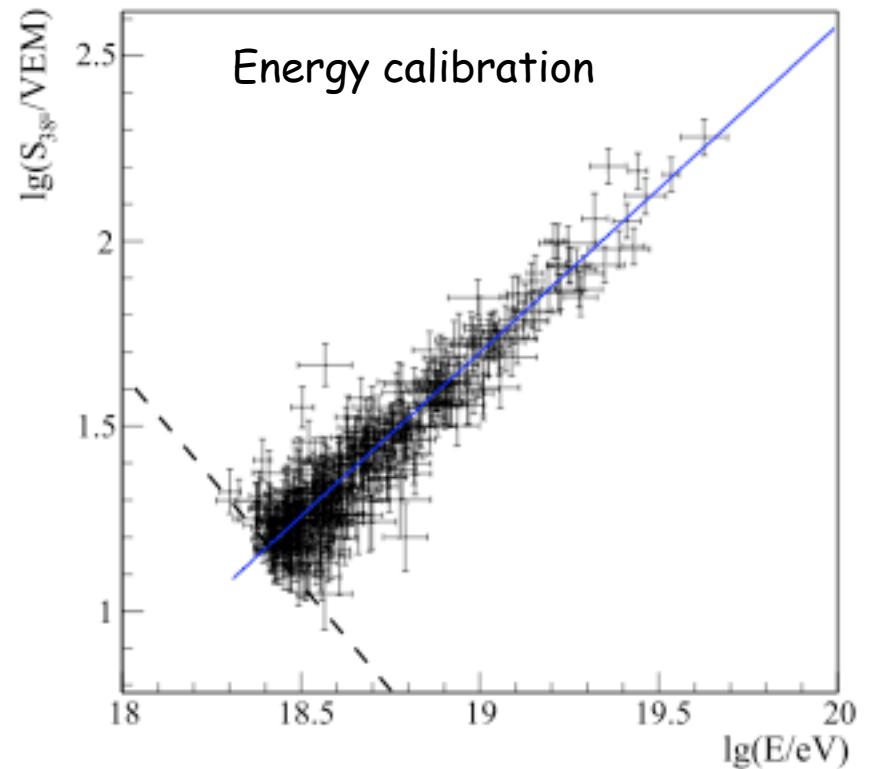
Constant Intensity Cut



Energy Calibration



$$S_{38} = S(1000) / f(\theta)$$



$$\log_{10}(E) = A + B \log_{10}(S_{38})$$

Publicity

Observatoire Pierre Auger
Explorateur d'Événements Publics

Explorateur d'Événements Publics

Bienvenue sur l'Explorateur d'Événements de l'Observatoire Pierre Auger !

La collaboration Pierre Auger a décidé de rendre public 1% de ses données. Ce site web permet de parcourir les événements collectés depuis Janvier 2004, il est mis à jour quotidiennement.

On peut sélectionner un événement donné en entrant directement son numéro, rechercher un événement avec le menu permettant de choisir un certain nombre de critères, ou plus simplement en choisissant un événement encore disponible en mémoire. Vous pouvez également télécharger le [fichier ASCII](#) avec tous les événements.

Le fichier de données courant a 5312 événements entre 0.1 et 37.4 EeV. Le dernier événement est le [3303300](#) et a été enregistré le 08/04/2007 05:30:02, UTC.

Événements en mémoire

3 événements les plus visités

| Étoile | Événement | Visualisation |
|--------|--------------|---------------|
| ☆☆☆ | 000004128900 | |
| ☆☆ | 000001234800 | |
| ☆ | 000004104600 | |

Observatoire Pierre Auger
Explorateur d'Événements

Sélection d'événements

| | Min | Max |
|----------------|-----|-----|
| Nb. de cuves | 5 | |
| Angle zénithal | 0 | 60 |
| Énergie (EeV) | 5 | |

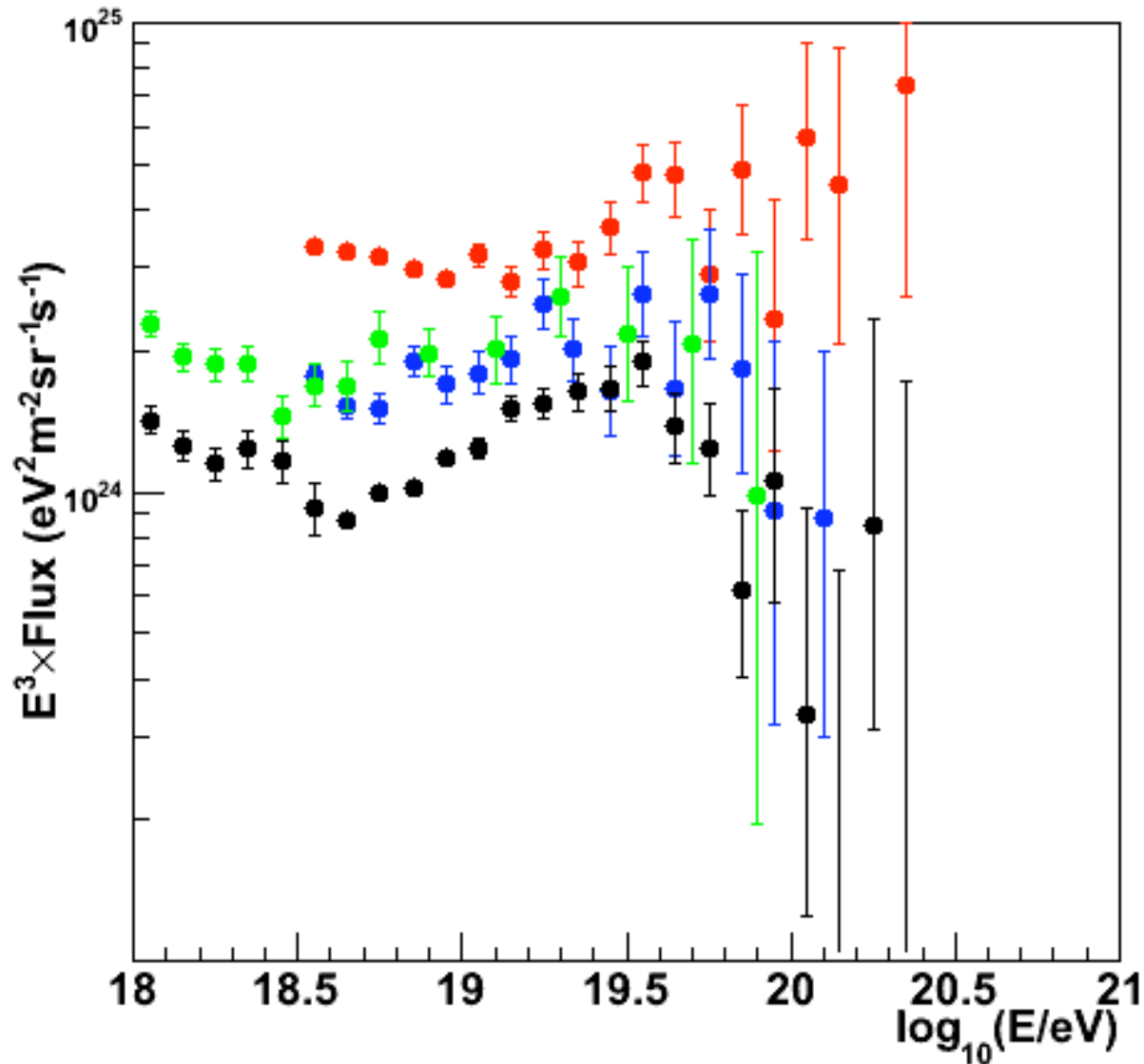
Ordre: N° / Date (Inverse) ▾
Montrer: 10 ▾ Événements
Chercher

Voir l'év. N° 1234800

Page hébergée par APC@IN2P3

1% of Auger events are public and available on :
<http://apcpaox.in2p3.fr/ED/index.php>

Results: spectrum

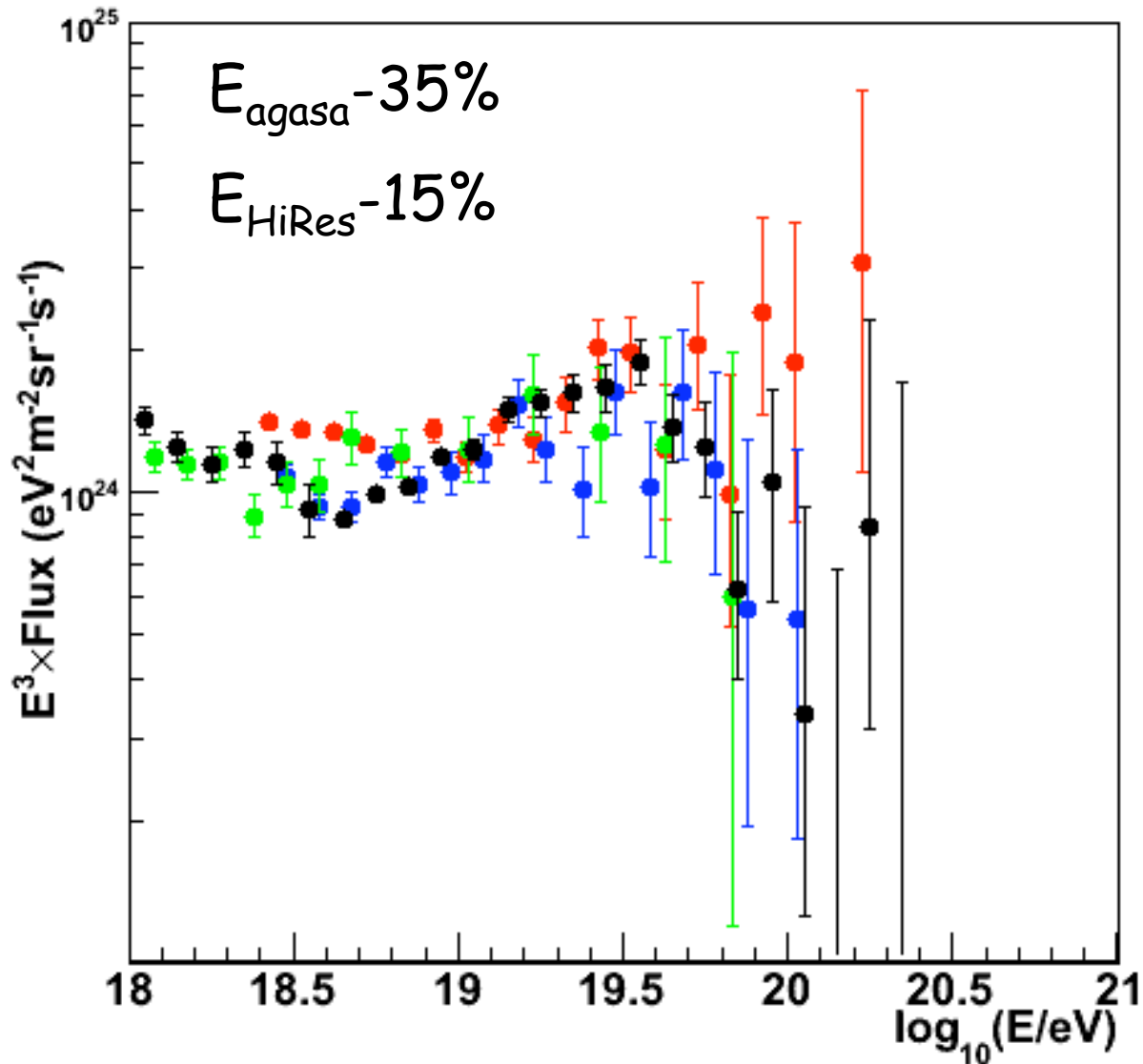


AGASA: surface array
(energy calibration from MC)

HiRes I-II: fluorescence
telescopes: aperture from MC

Auger: direct measurement of
energy, geometric aperture

Results: spectrum



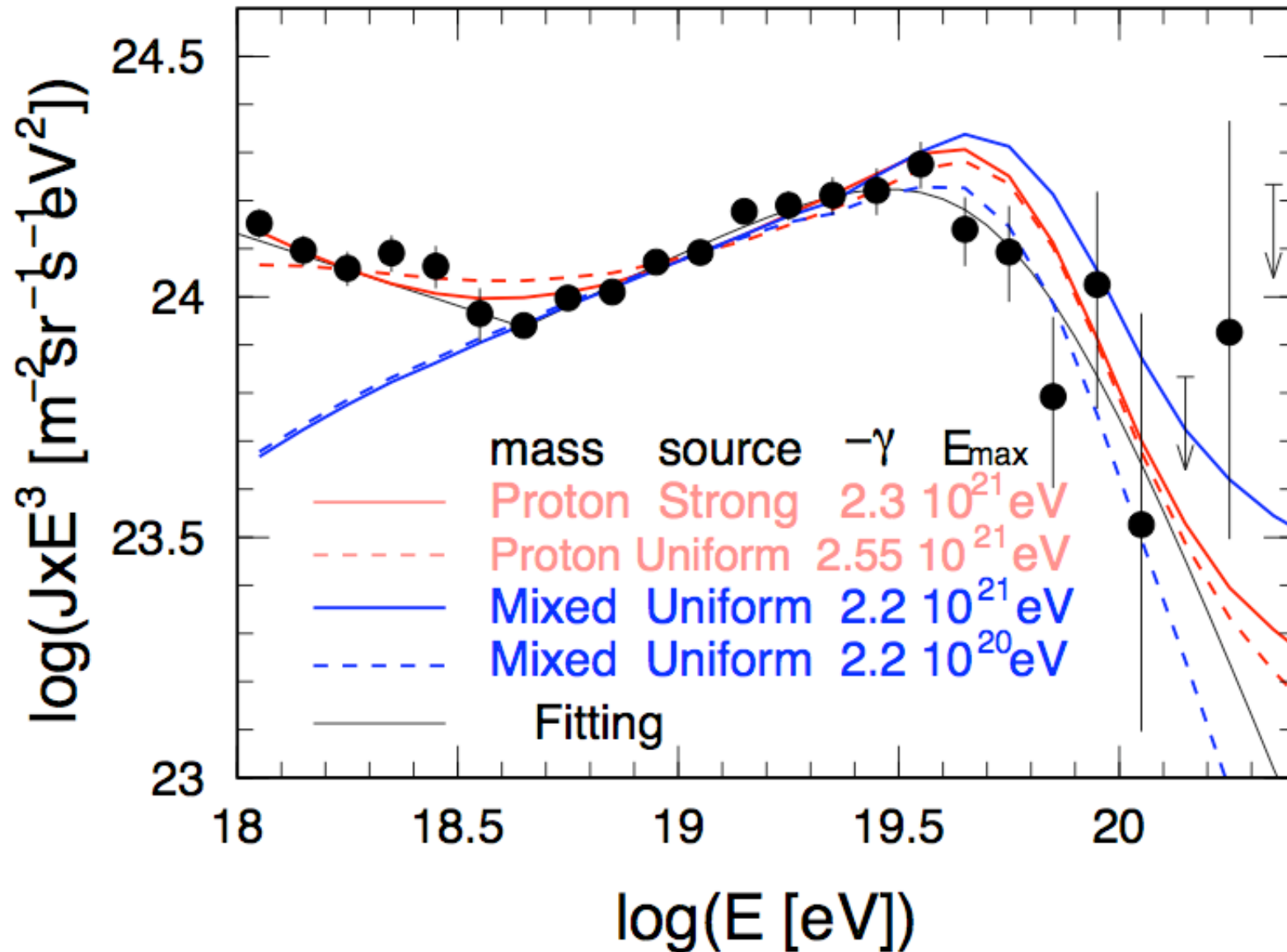
AGASA: surface array
(energy calibration from MC)

HiRes I-II: fluorescence
telescopes: aperture from MC

Auger: direct measurement of
energy, geometric aperture

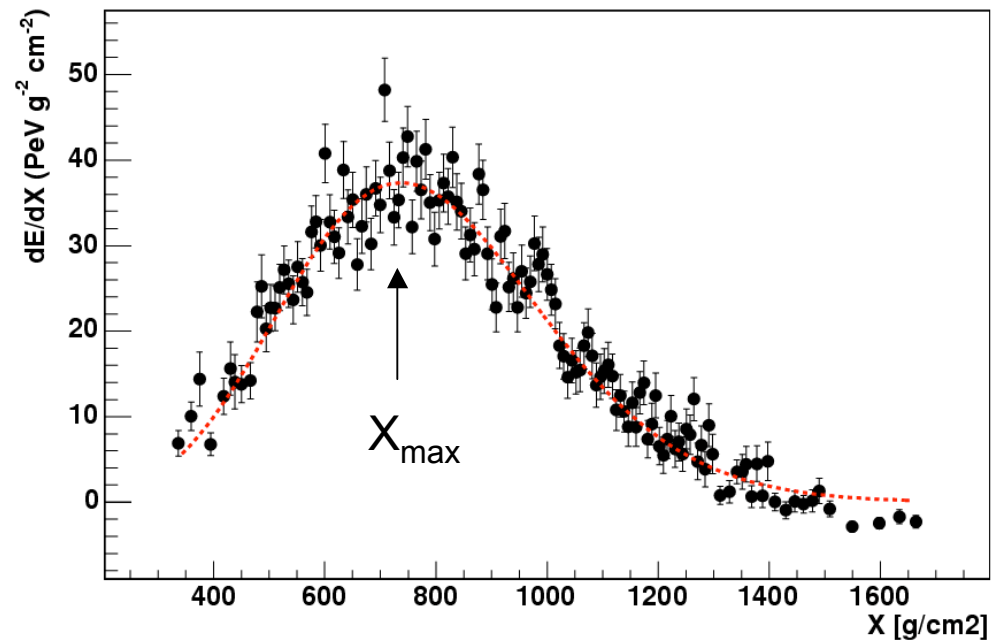
GZK cutoff
observed with 6σ
significance

Spectrum interpretation

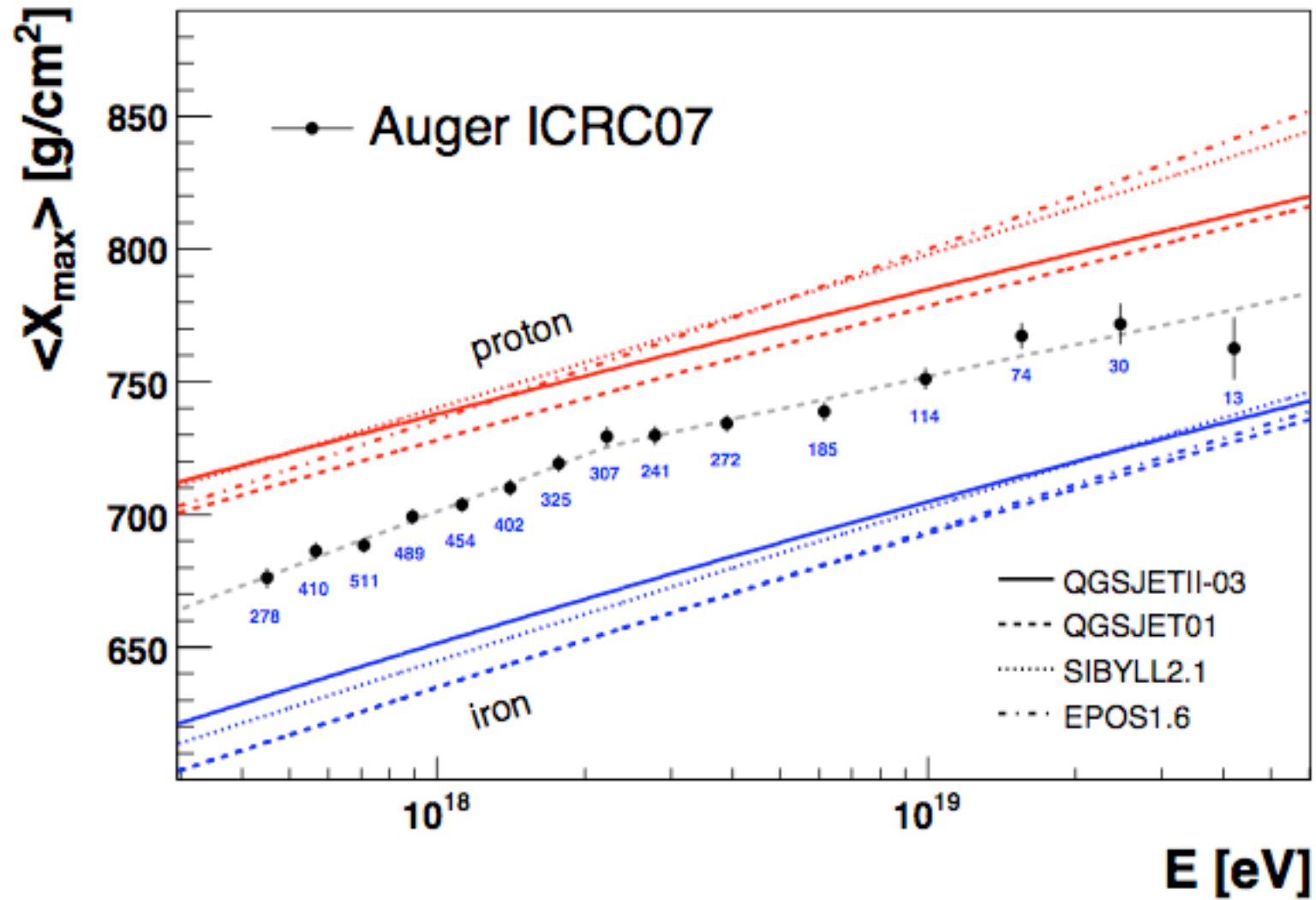


Results: Composition

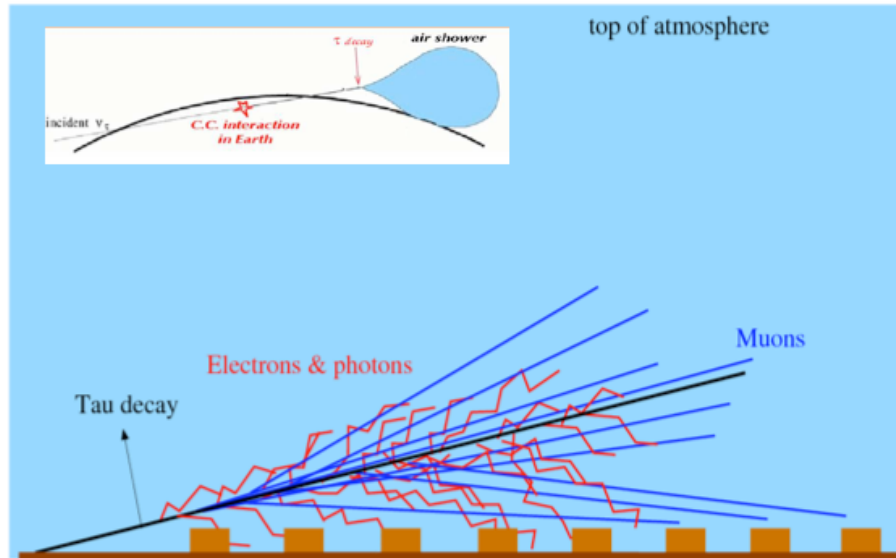
Method:



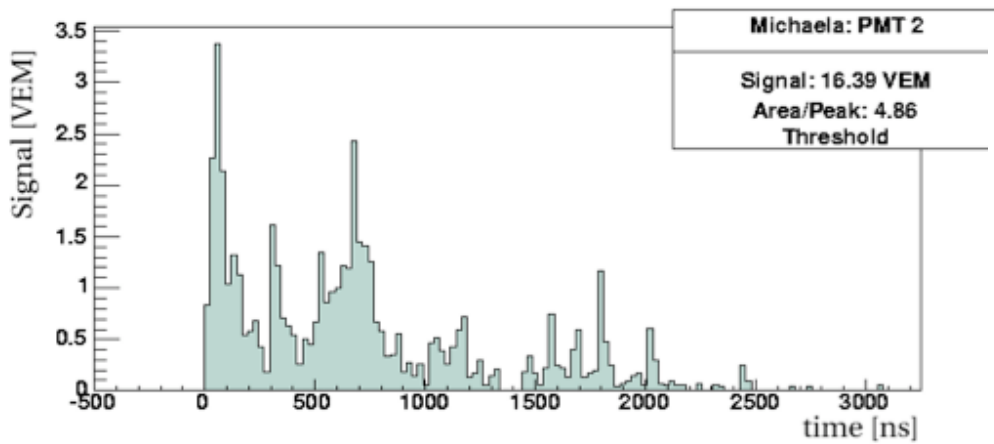
Results: Composition



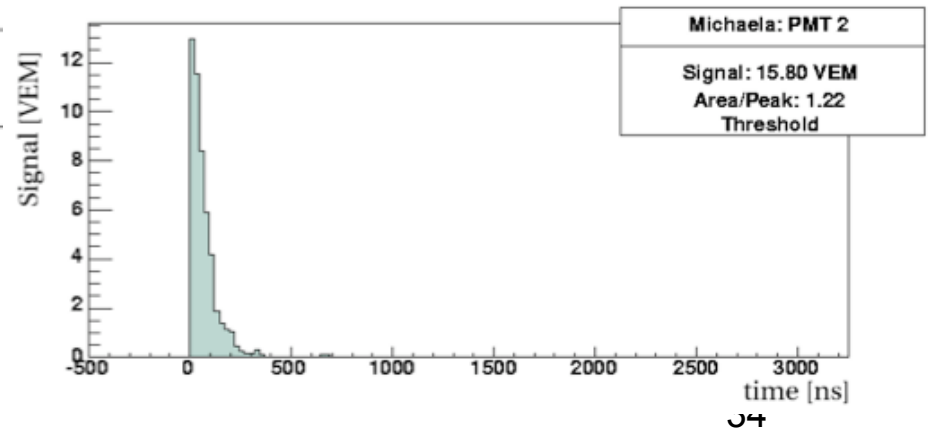
Results: Neutrino Limits



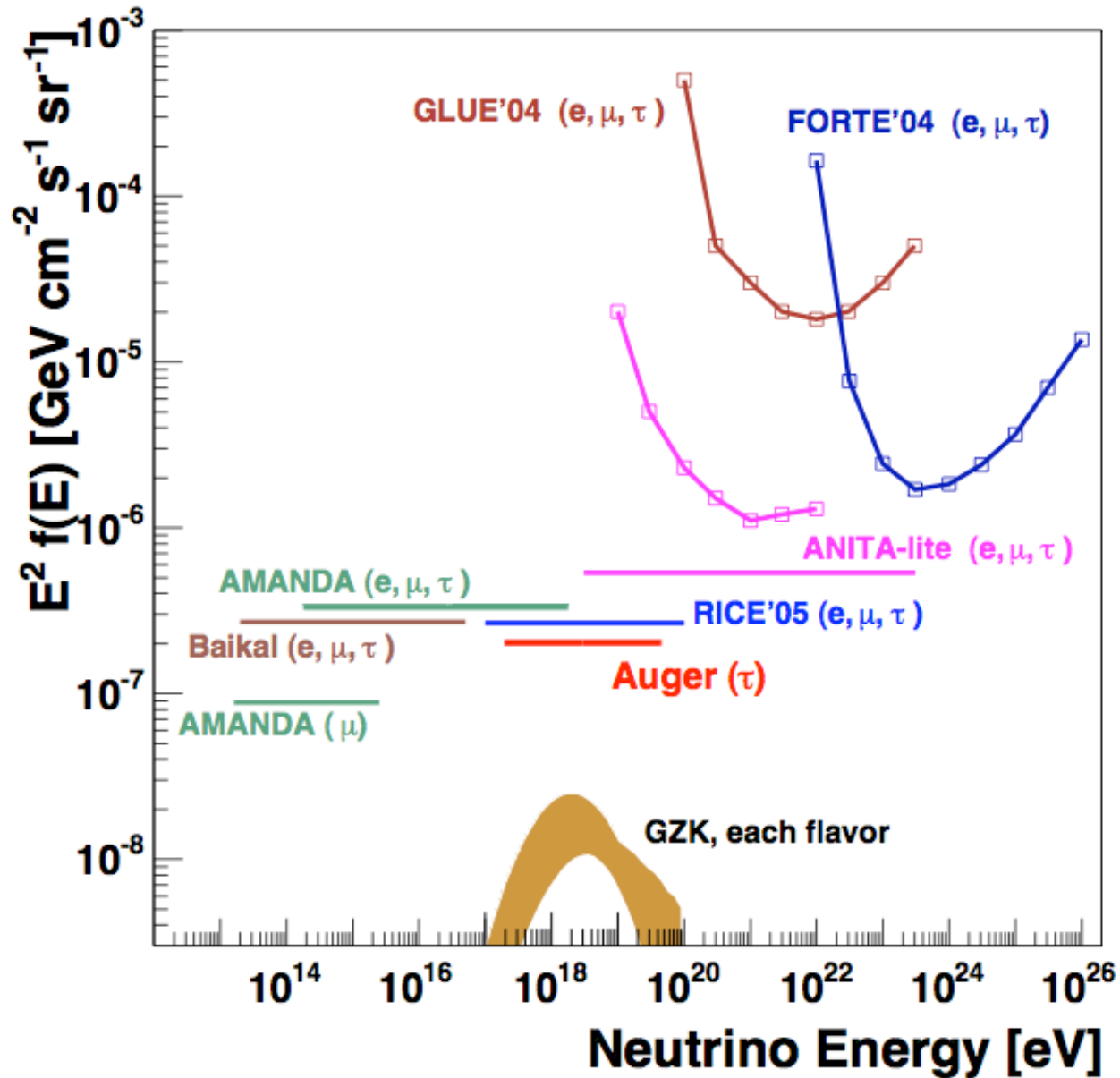
"young" signal



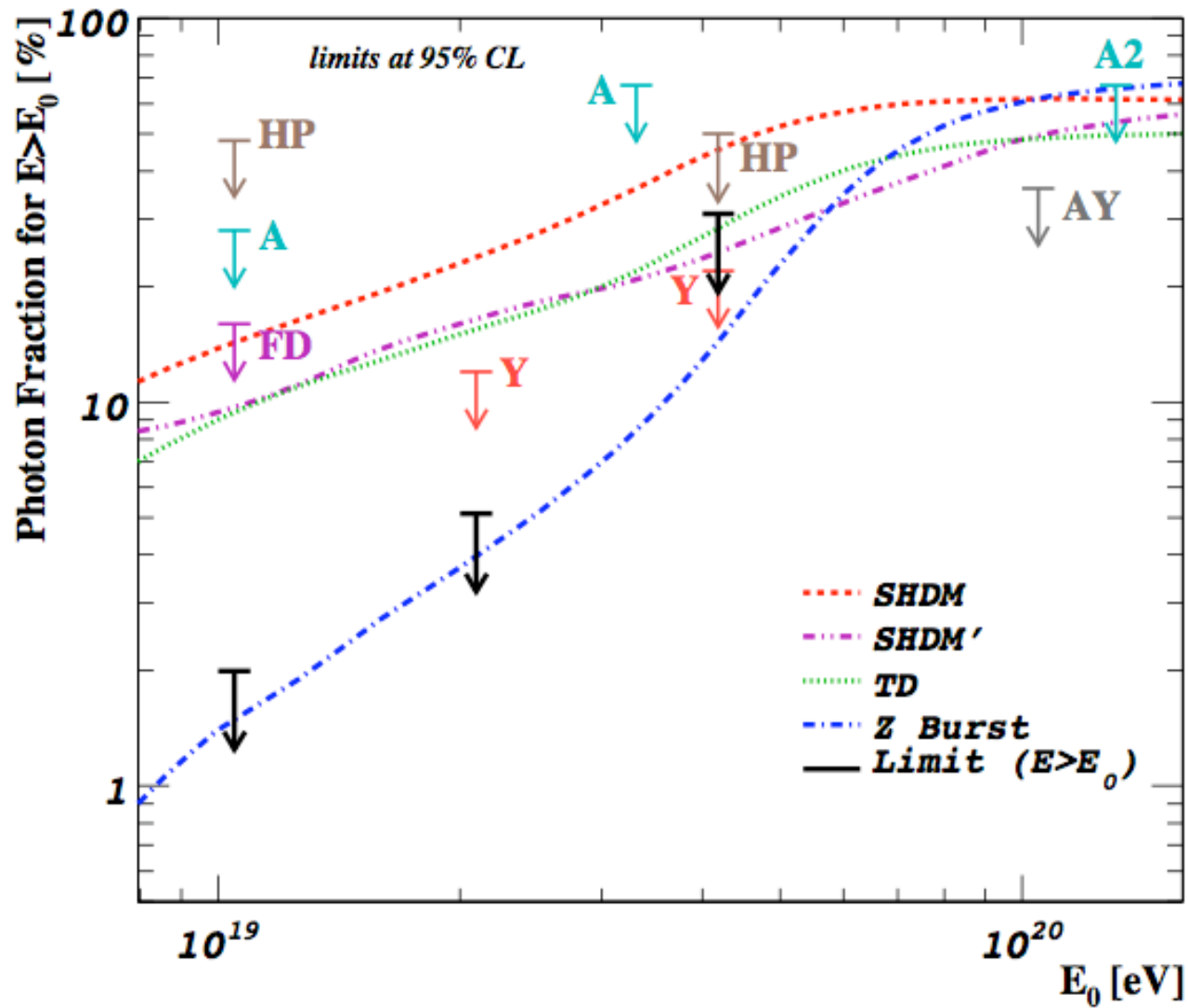
"old" signal



Results: Neutrino Limits



Results: Photon Limits



Possible sources of UHECRs

Hillas diagram :

Acceleration limited by size and magnetic field E_{\max}

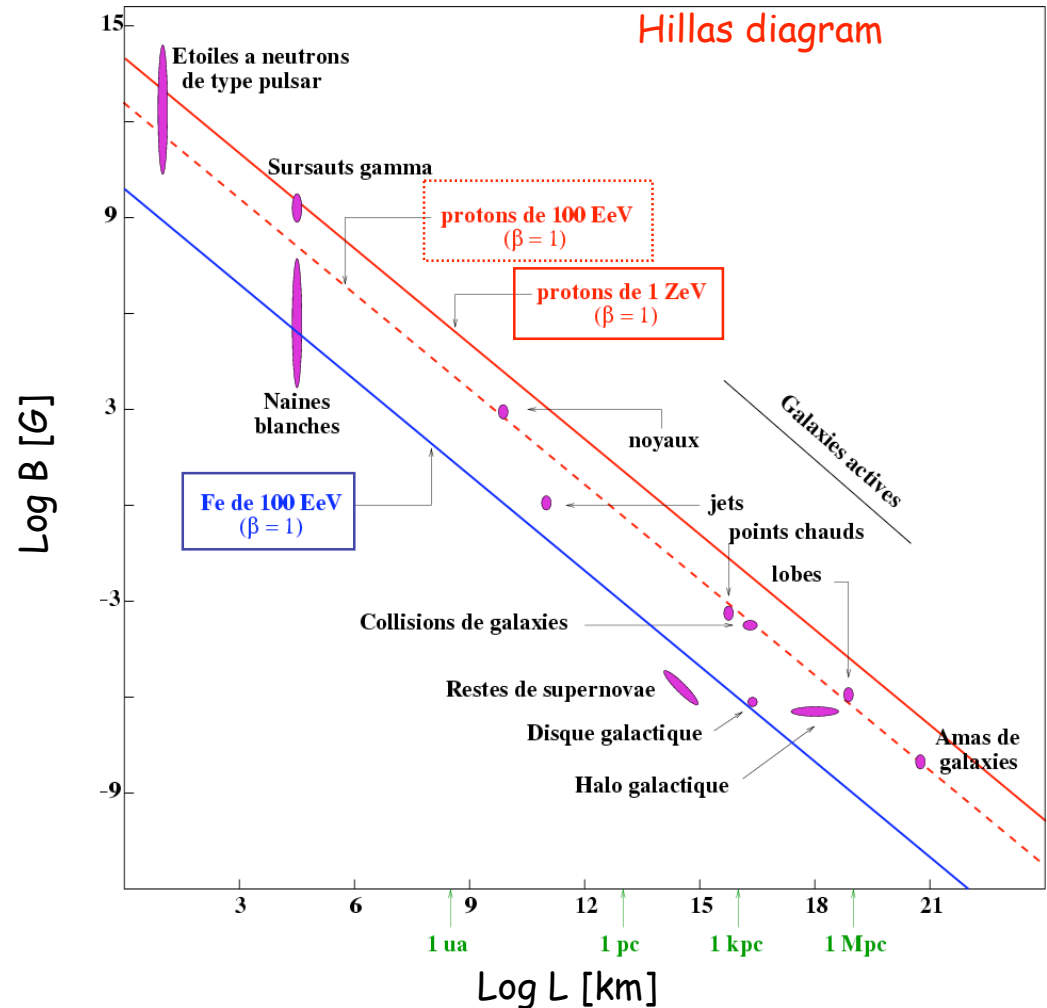
$$r_L = E / (Z \cdot B) < L$$

Larmor radius

Size of the accelerator

Not take into account :

- ✓ acceleration mechanism
- ✓ energy losses



Possible sources of UHECRs

Hillas diagram :

Acceleration limited by size and magnetic field E_{\max}

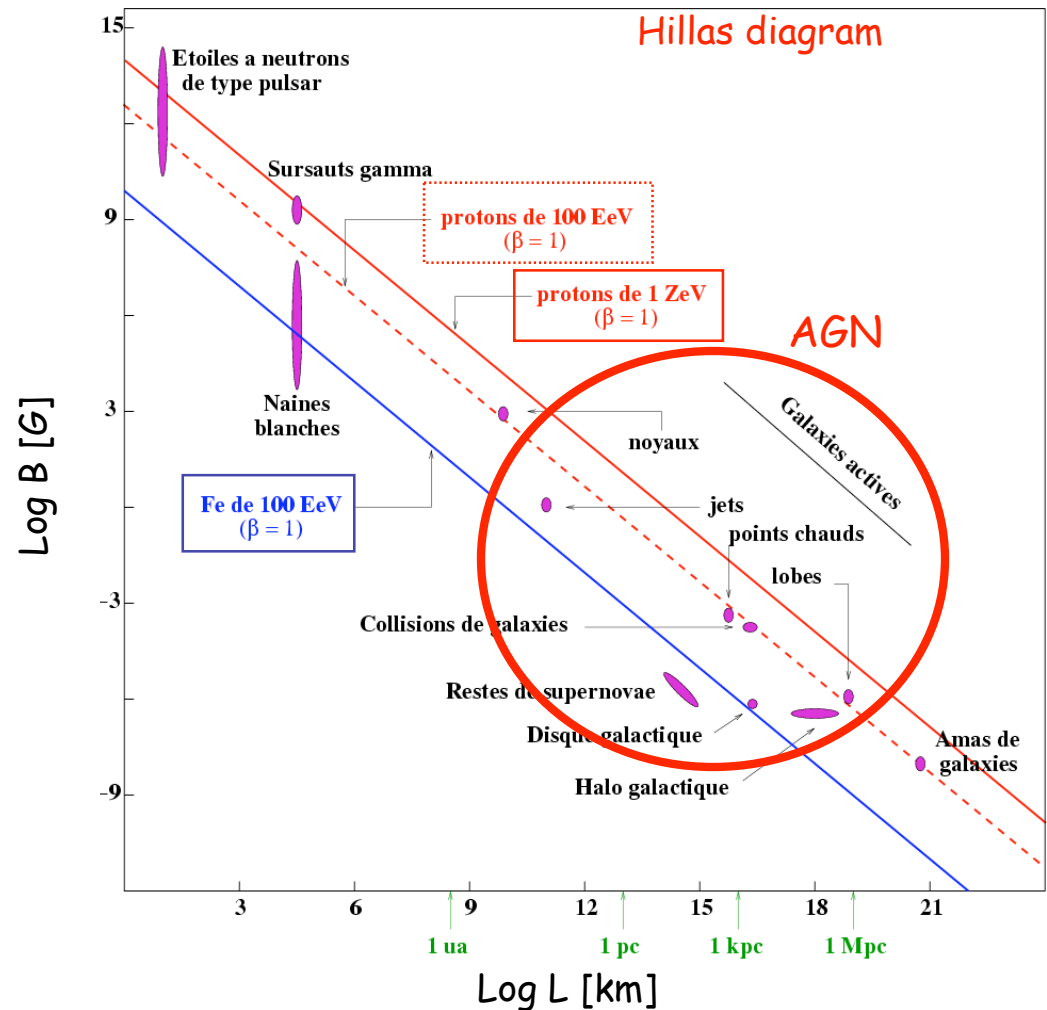
$$\vec{r}_L = E / (Z \cdot B) < L$$

Larmor radius

Size of the accelerator

Not take into account :

- ✓ acceleration mechanism
- ✓ energy losses



Results: Anisotropies



Nov. 2007

The analysis:

Two stages:

- before May 26th 2006 - exploration
- after May 26th 2006 - confirmation

prescription

Anisotropies : Exploration

Compared the data with the Veron-Cetty & Veron 12th catalogue of AGN:

- Correlation: $\text{angle}(\text{AGN}, \text{data}) < \theta_{\text{cut}}$
- AGNs: up to $D < D_{\text{max}}$
- Data: $E > E_{\text{min}}$

$$P_{\text{iso}} = \sum_{i=ncorr}^N p^i (1-p)^{N-i} \quad p = \text{probability of falling within } \theta_{\text{cut}} \text{ from an AGN}$$

P_{iso} is minimized with respect to θ_{cut} , D_{max} and E_{min}

Results: $\theta_{\text{cut}} = 3.1^\circ$, $D_{\text{max}} = 75 \text{ Mpc}$, $E_{\text{min}} = 56 \text{ EeV}$

Correlation: 12/15 (expected from isotropy: 3.2/15)

Anisotropies : Prescription

(Decided on may 26th 2006)

For each event *after 26 May 2006*:

- check if it correlates with an AGN for fixed parameters $\theta_{\text{cut}} = 3.1^\circ$, $D_{\text{max}} = 75 \text{ Mpc}$, $E_{\text{min}} = 56 \text{ EeV}$ (« running prescription »)
- if the number of correlations is above a predefined threshold, the prescription is said to pass

Anisotropies : Prescription

(Decided on may 26th 2006)

For each event *after 26 May 2006*:

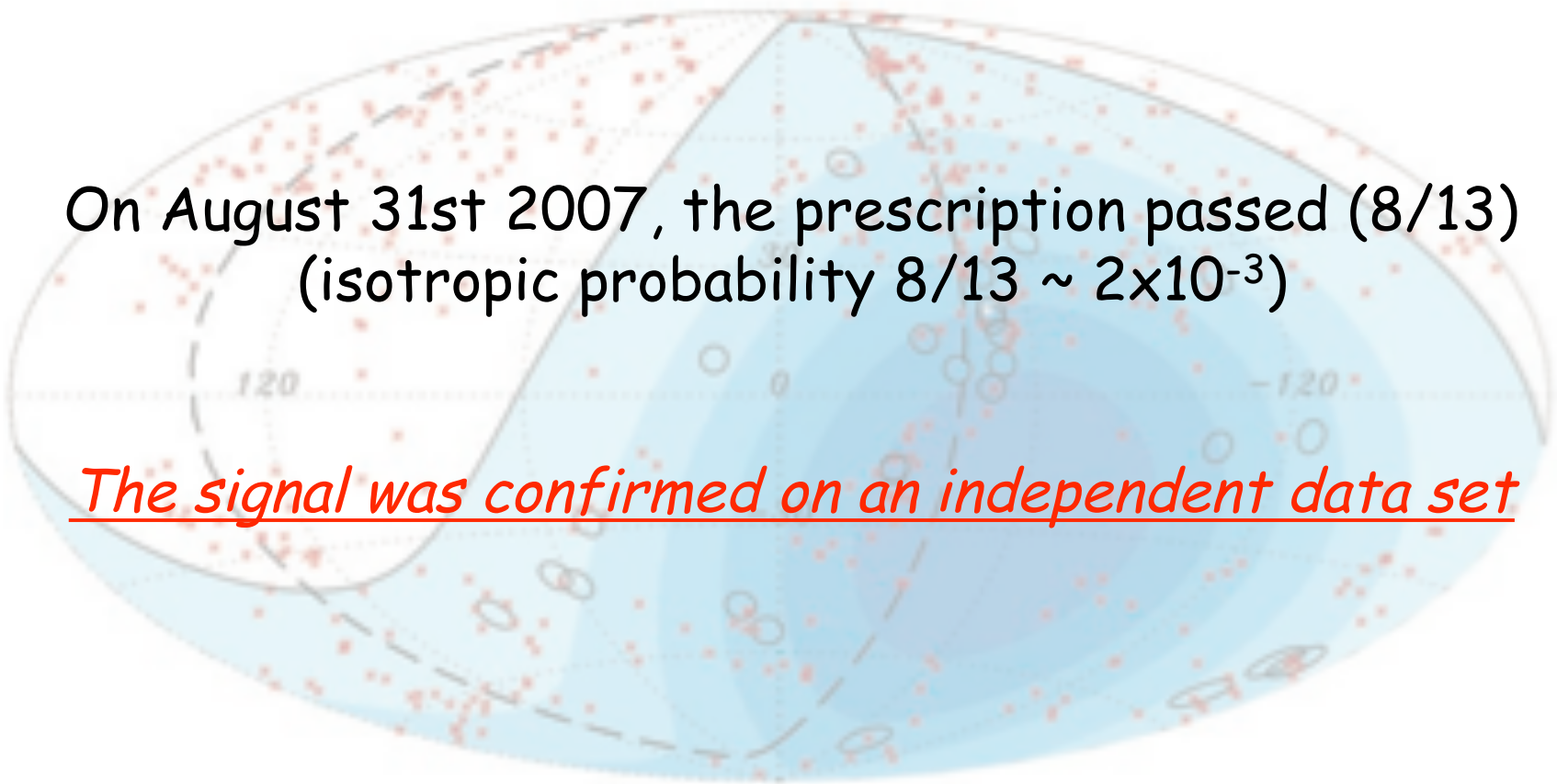
- check if it correlates with an AGN for fixed parameters $\theta_{\text{cut}} = 3.1^\circ$, $D_{\text{max}} = 75 \text{ Mpc}$, $E_{\text{min}} = 56 \text{ EeV}$ (« running prescription »)
- if the number of correlations is above a predefined threshold, the prescription is said to pass

The prescription had a 1% chance of passing for an isotropic flux

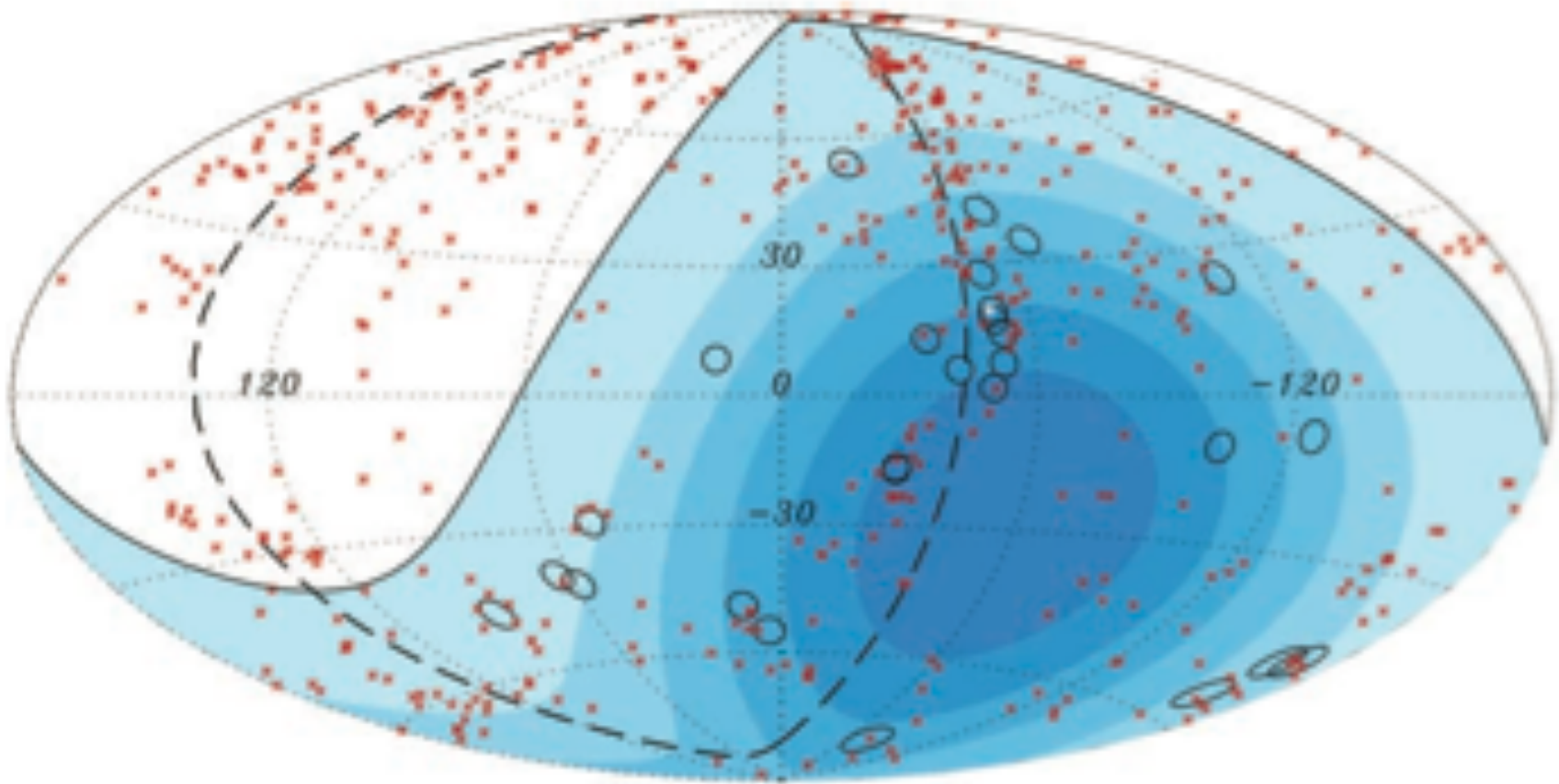
Anisotropies : Confirmation

On August 31st 2007, the prescription passed (8/13)
(isotropic probability $8/13 \sim 2 \times 10^{-3}$)

The signal was confirmed on an independent data set



Anisotropies : Results



○ Auger events

■ Sky covered by Auger

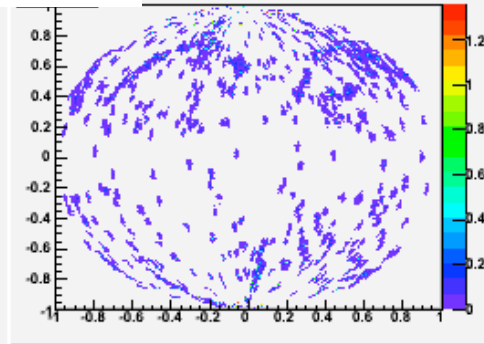
● AGNs

Total of 20/27 correlating
(isotropy : 5.6)

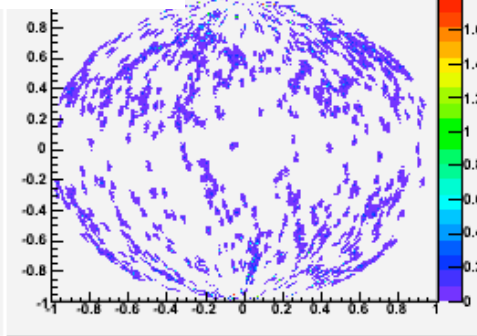
Anisotropies : Results

Smoothed VC catalog: galactic coordinates

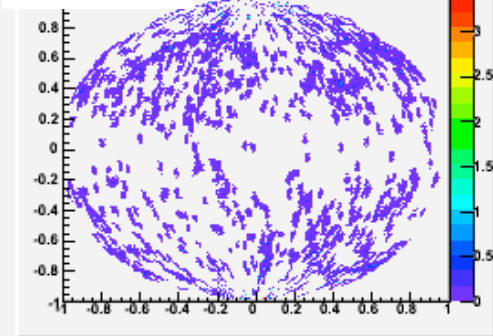
50 Mpc



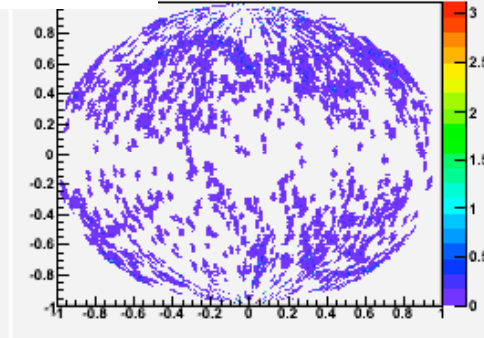
100 Mpc



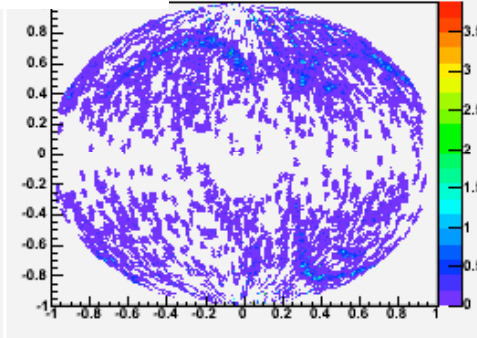
150 Mpc



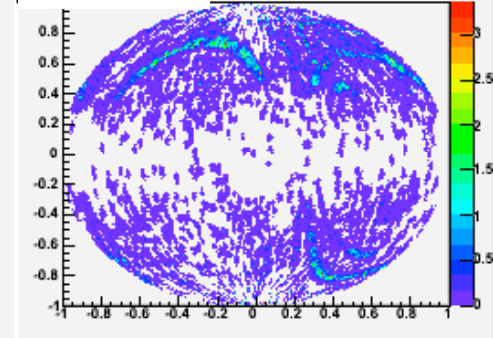
200 Mpc



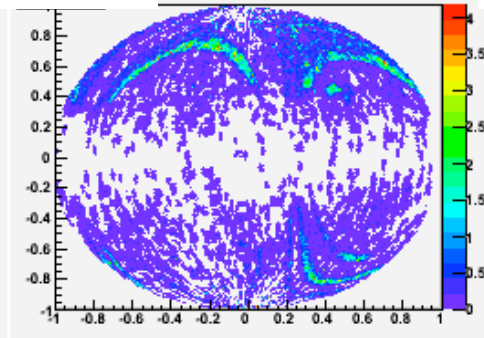
250 Mpc



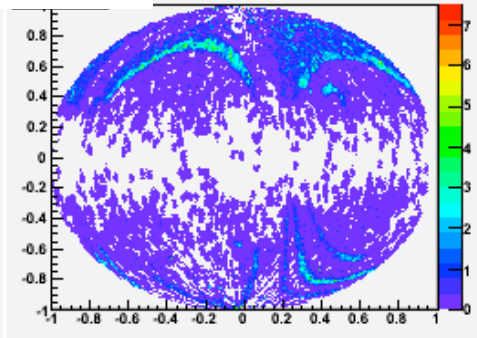
300 Mpc



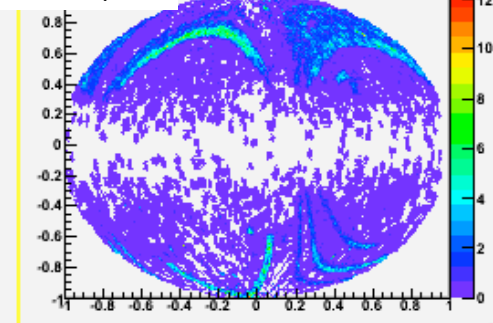
350 Mpc



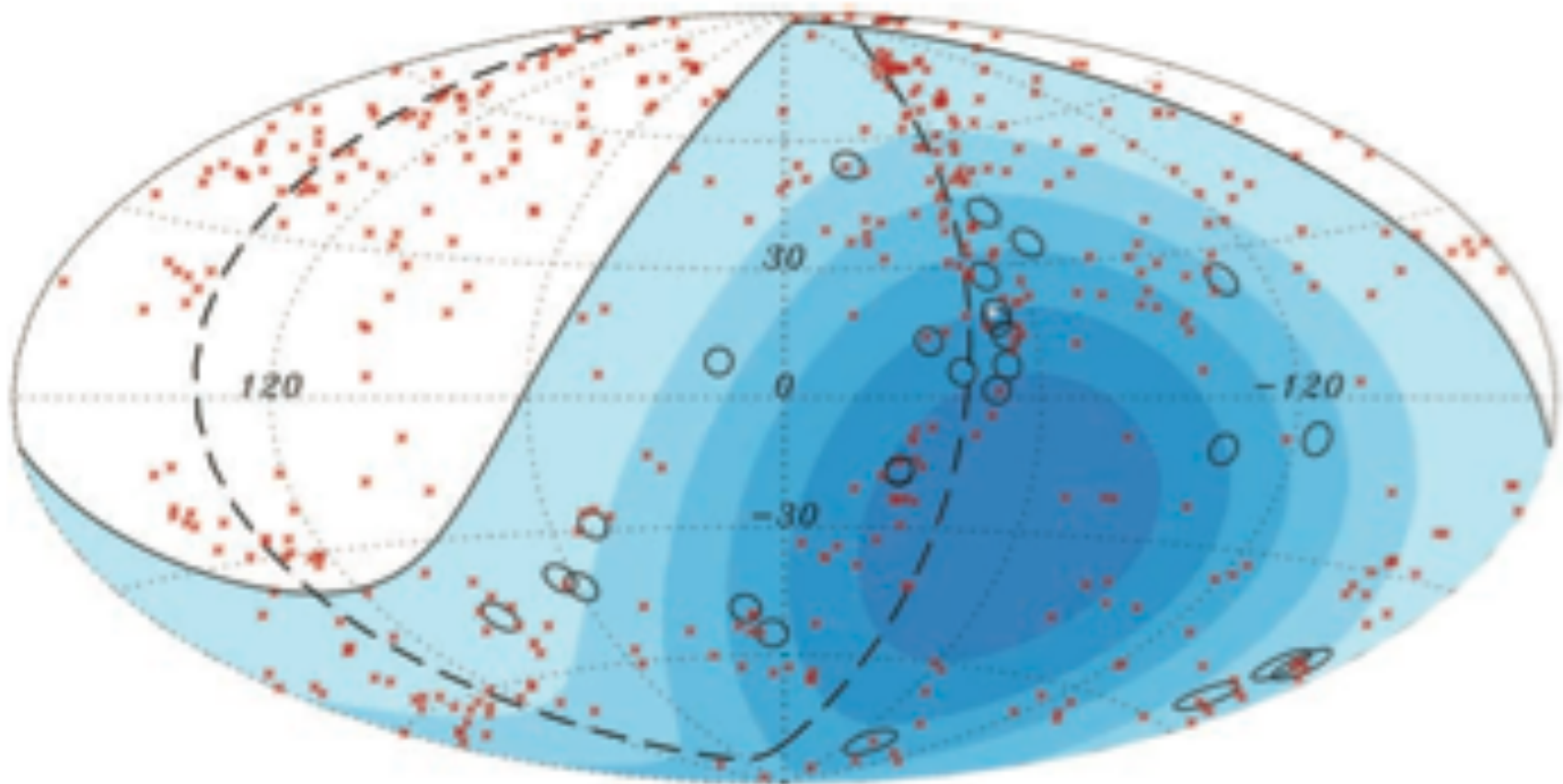
400 Mpc



450 Mpc



Anisotropies : Results



○ Auger events

■ Sky covered by Auger

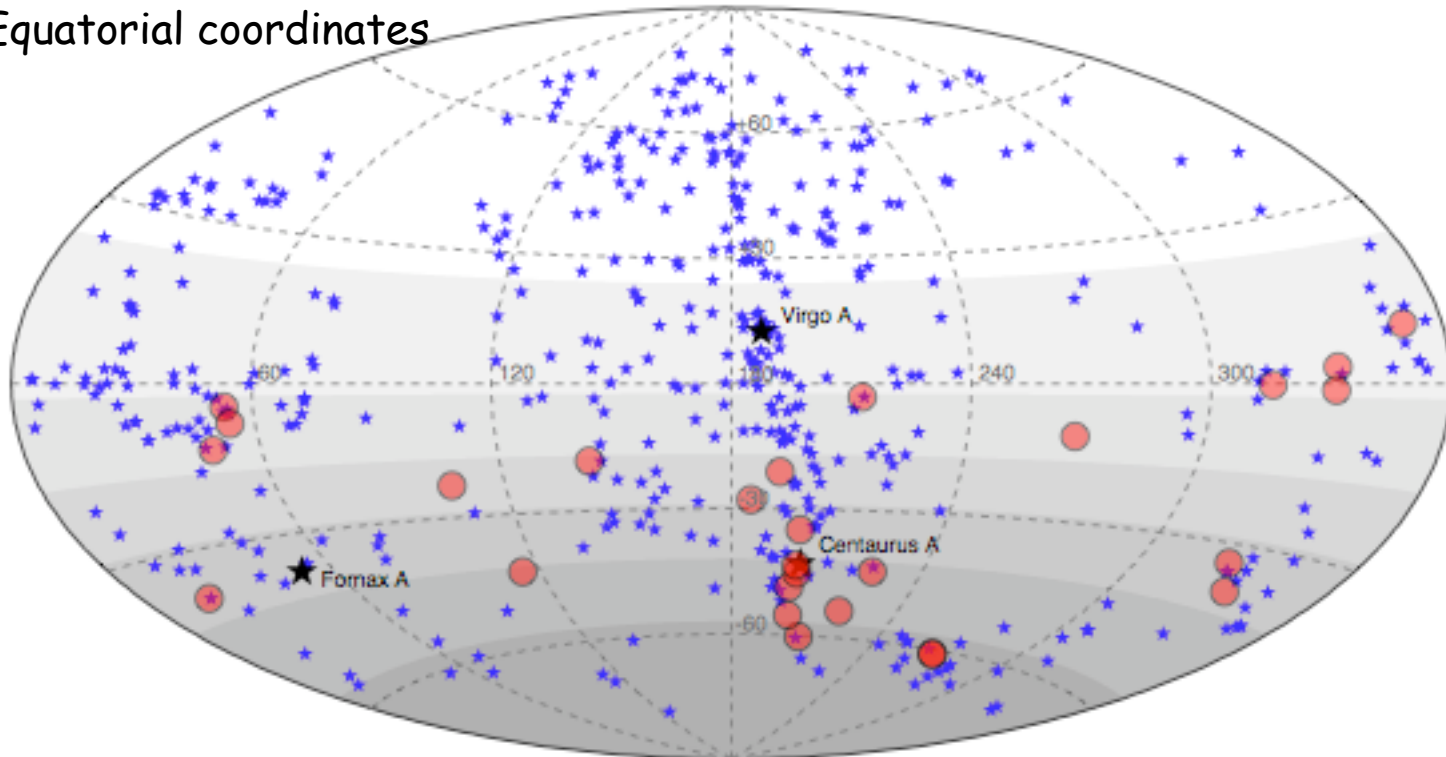
● AGNs

Total of 20/27 correlating
(isotropy : 5.6)

19/21 cutting off the Gal. Plane⁴⁶

Anisotropies : astrophysical objects

Equatorial coordinates



Anisotropies : Results

What do these results mean?

- UHECRs don't come from an isotropic distribution
- UHECRs come from the direction of an AGN (extragalactic origin)

This does not mean that:

- AGNs accelerate UHECRs
- We've found the sources of UHECRs

The Future

Near:

months: ~ three papers describing anisotropies in more technical detail

Middle-term:

1 year and a half: Auger will double the statistics

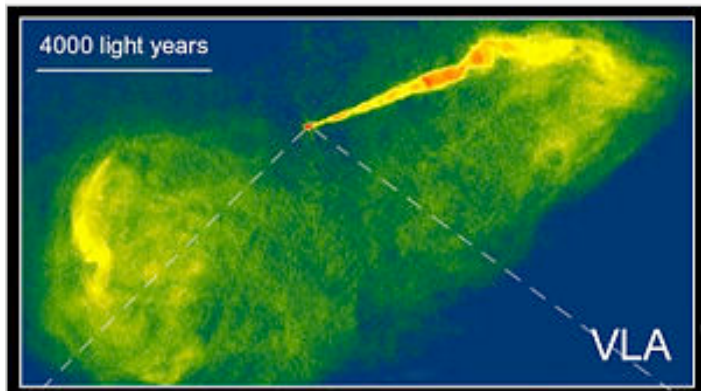
The Future

Long Term

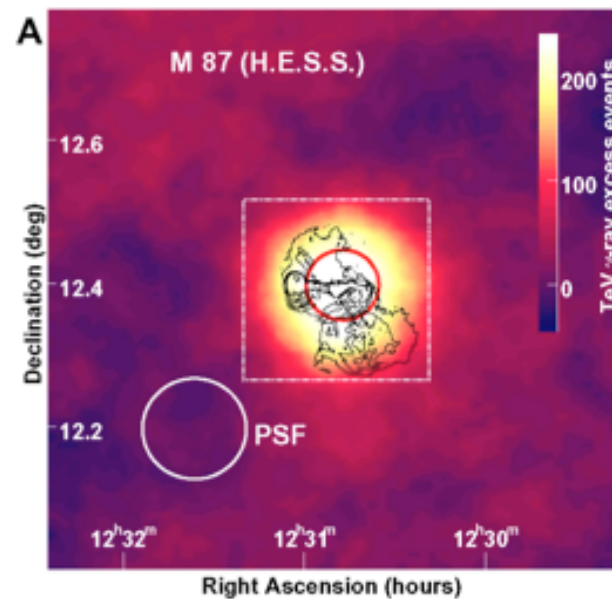
Years:

- Larger scale detectors, Auger North (7x A.S.), EUSO, etc.
- **UHECRs astronomy**

VLA (Radio)



HESS (Gamma)



AUGER?