RECENT RESULTS FROM THE PIERRE AUGER OBSERVATORY

(Neutrino 2008, Christchurch, NZ)

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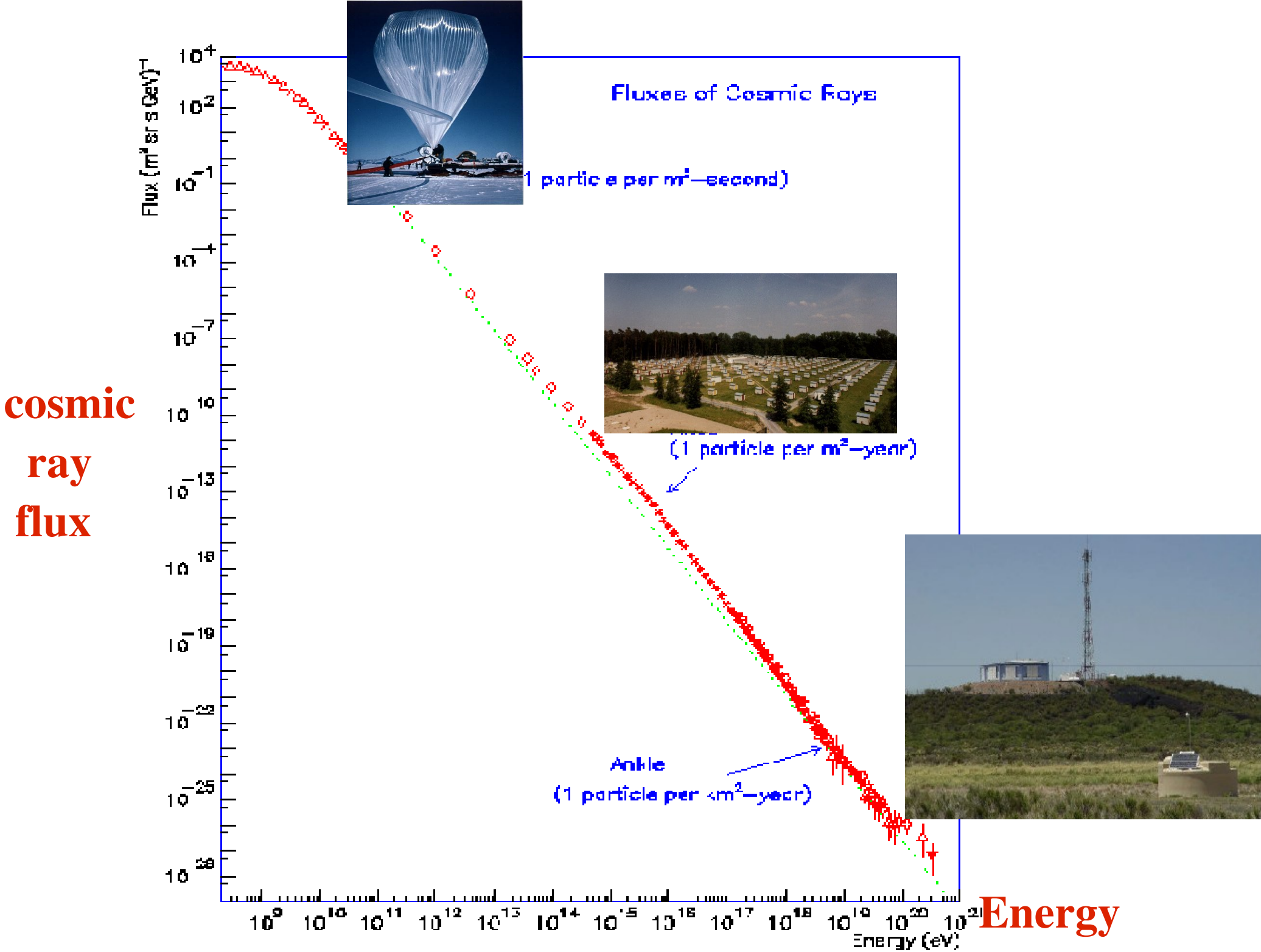
the Auger Collaboration: 17 countries, ~100 Institutions, ~400 scientists

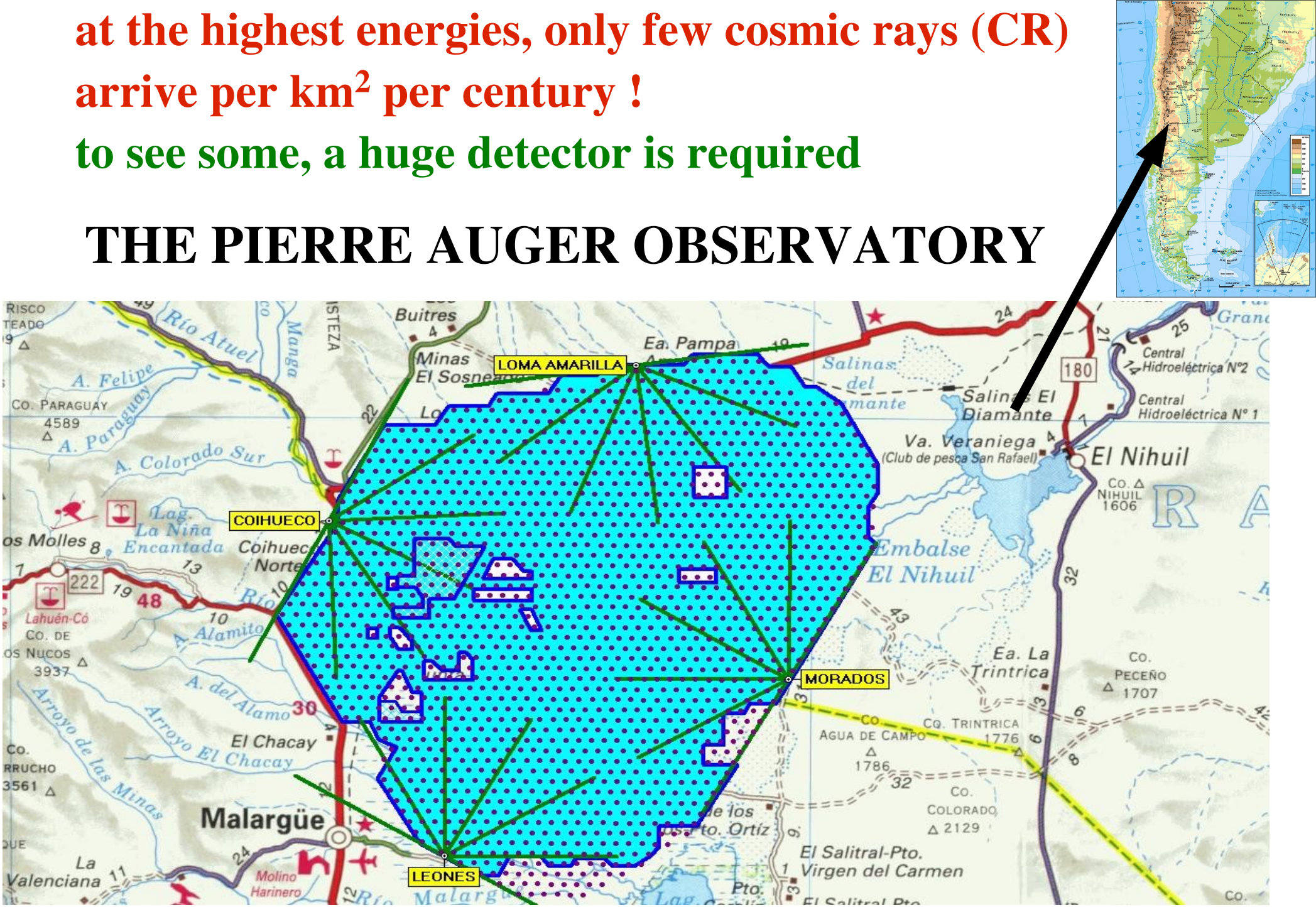
Argentina, Australia, Bolivia, Brazil, Czech Rep., France, Germany, Italy, Mexico, Netherlands, Poland, Portugal, Slovenia, Spain, UK, USA, Vietnam


cosmic
ray
flux
Fluxes of Cosmic Rays
(1 particle per m²—second)
(1 particle per m²—year)
Ankle
(1 particle per km²—year)
Flux (m² sr s GeV)⁻¹
Energy (eV)
Energy

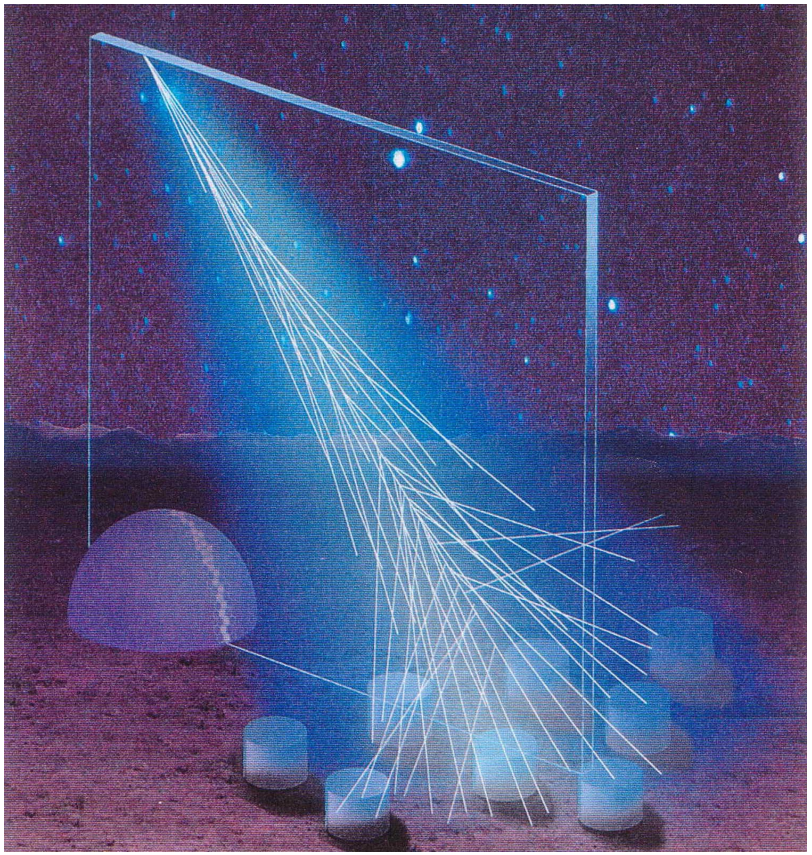
at the highest energies, only few cosmic rays (CR) arrive per km^2 per century !

to see some, a huge detector is required

THE PIERRE AUGER OBSERVATORY



1600 detectors instrumenting 3000 km^2 and 24 telescopes



HYBRID DESIGN

Surface Detectors:

"statistical power" to detect showers on the ground

Fluorescence Detectors:

complementary view of the shower development

energy cross-calibration
angular resolution tests,
X_{max} measurements, etc.

SCIENTIFIC OBJETIVES:

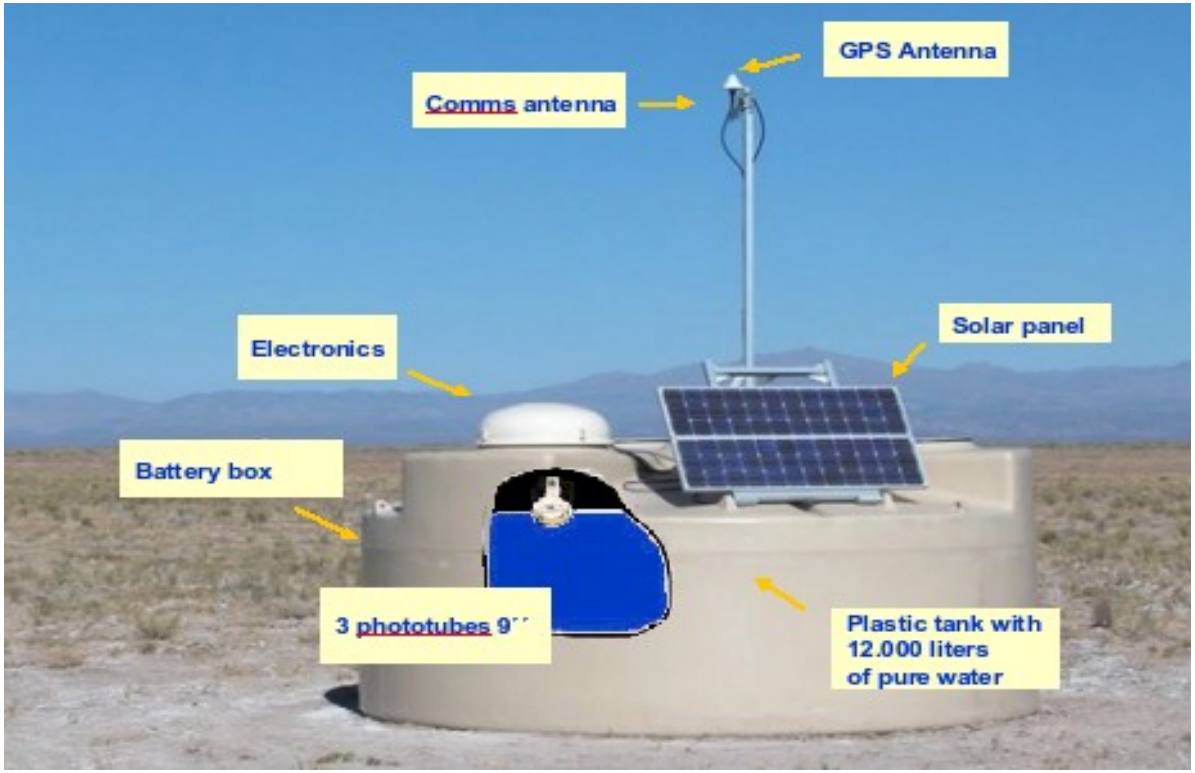
Spectrum: CR flux for E > 10^{18} eV

Arrival directions: search for anisotropies (sources)

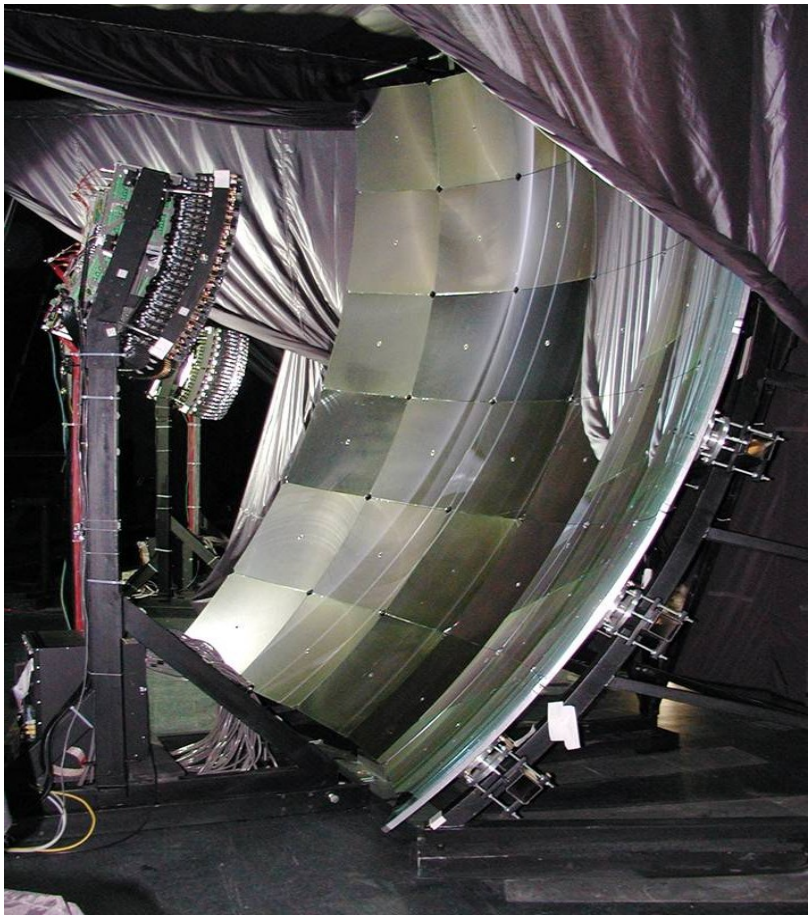
Composition: light or heavy nuclei, photons, neutrinos, others?

Study of interactions at energies unreachable at accelerators

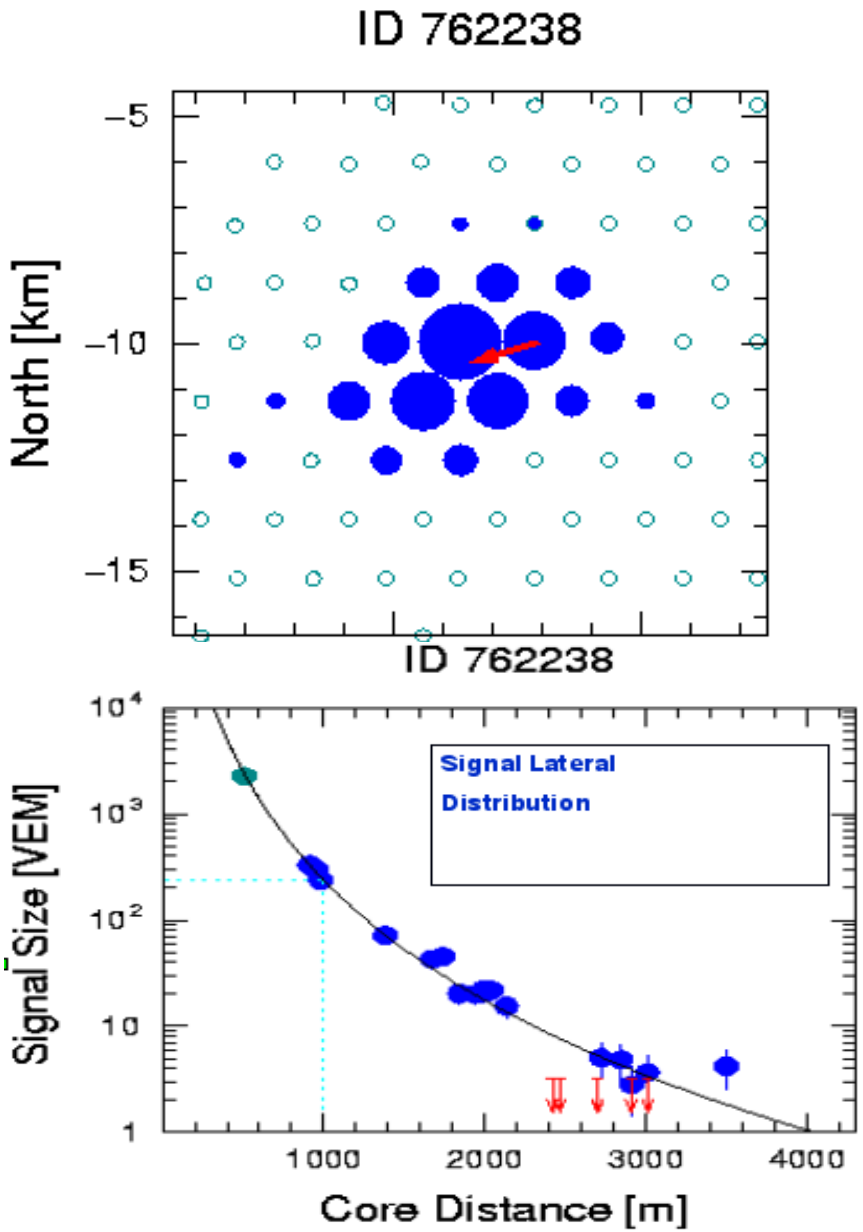
surface detector

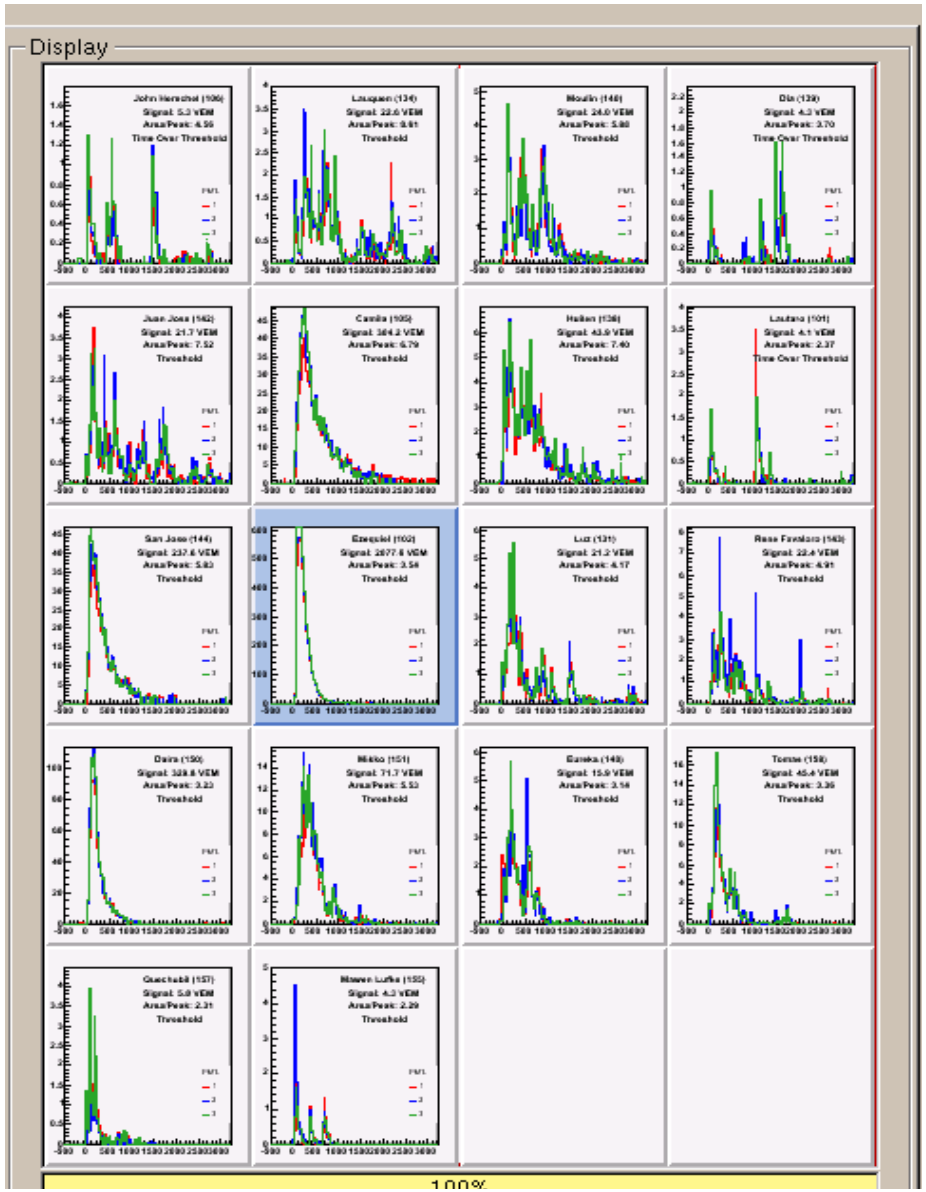


fluorescence detector



event reconstruction with the surface detector

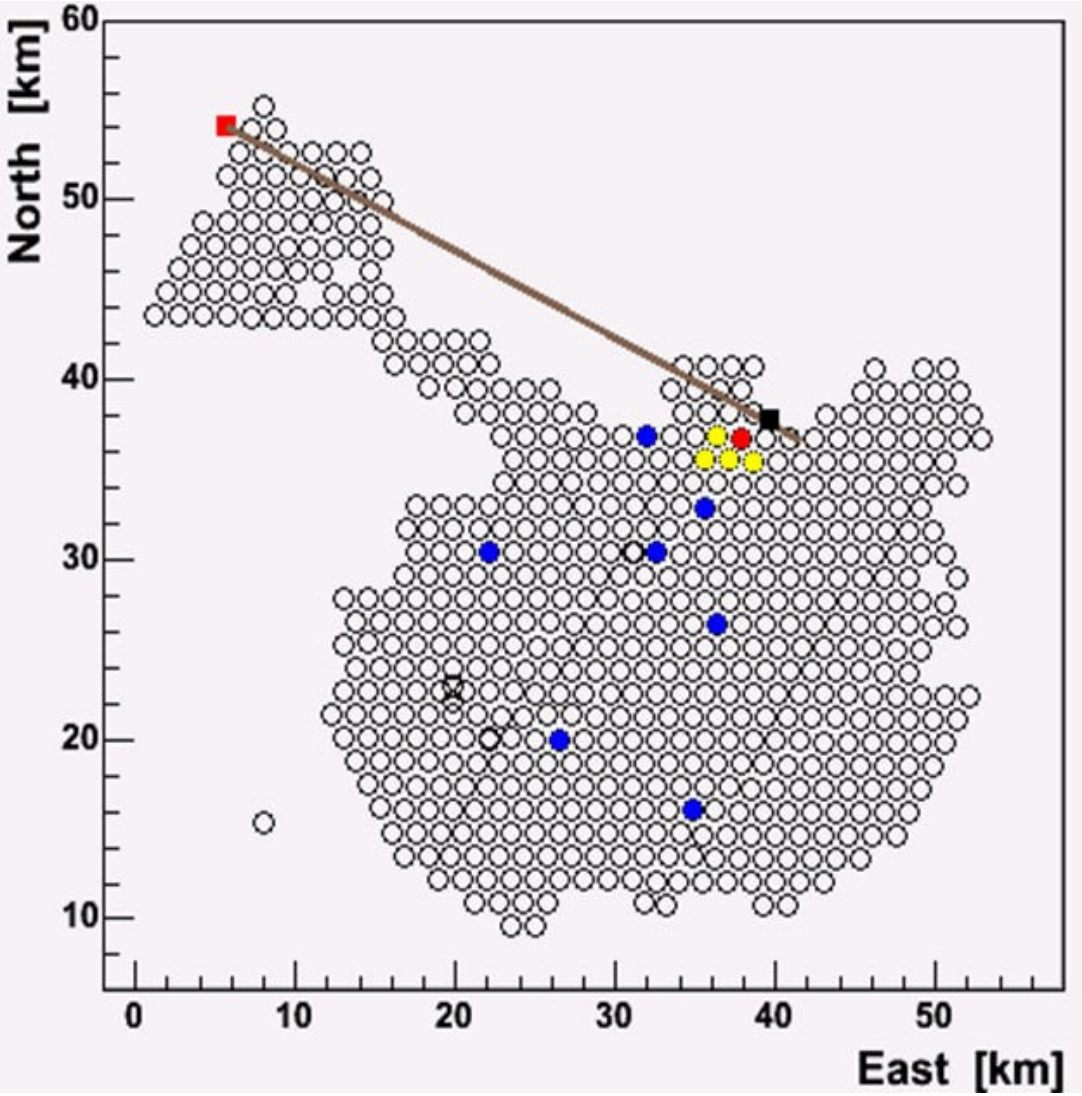


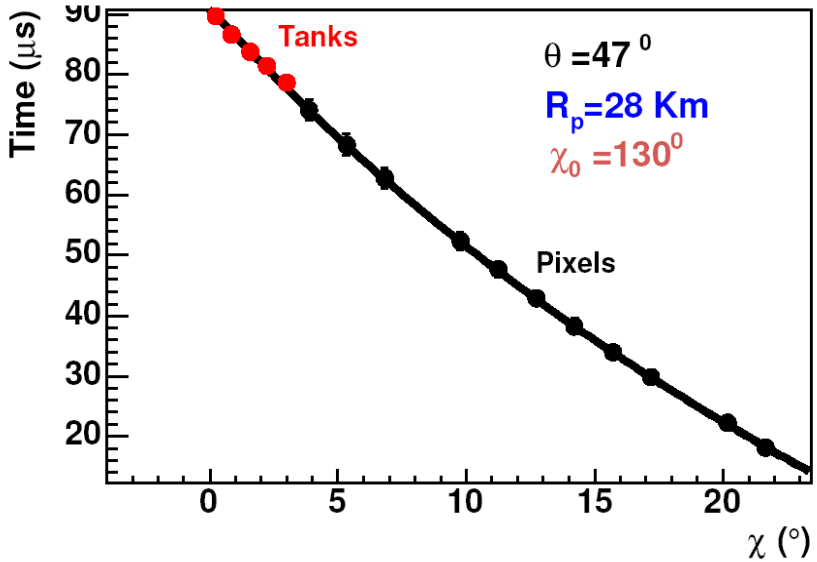


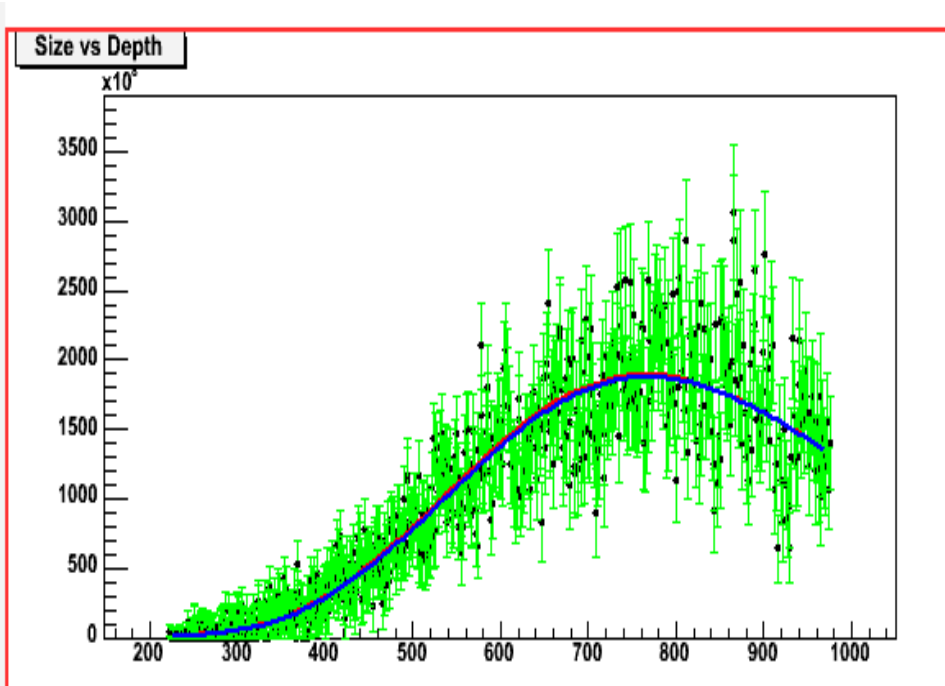
Event with θ~ 48º, E ~ 70 EeV

(1 EeV = 10^{18} eV)

a hybrid event

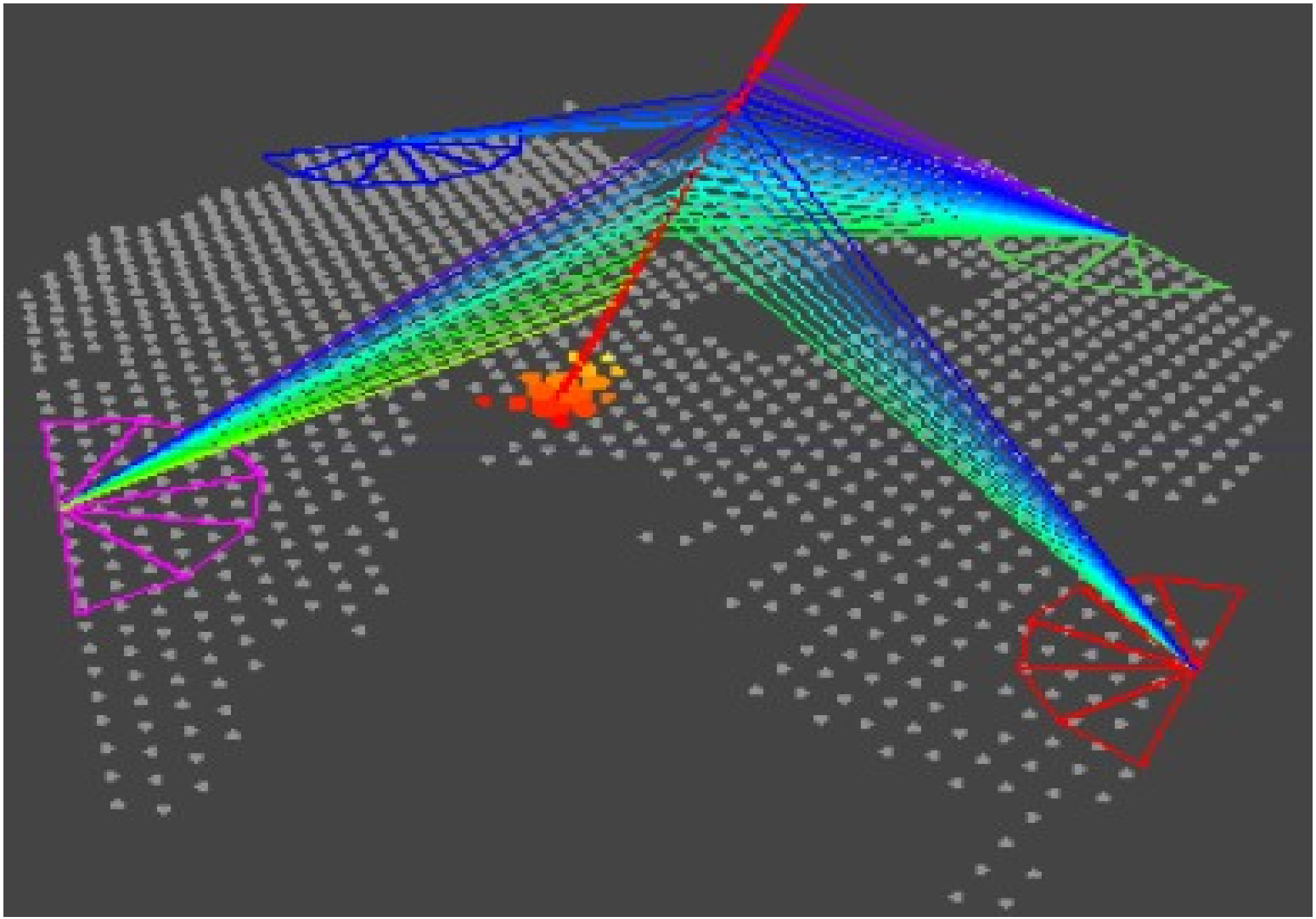




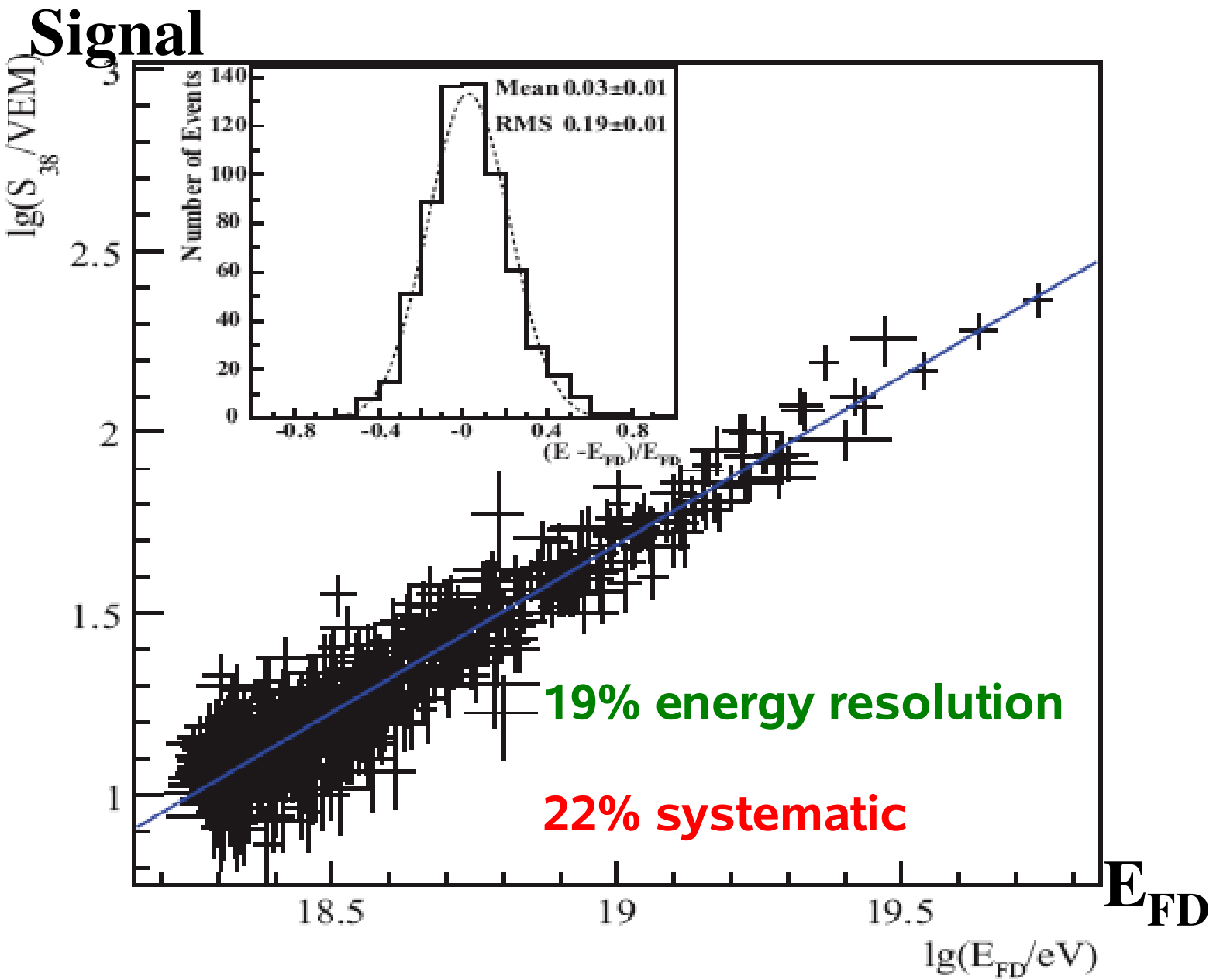


(E > 1.4 x 10^{20} eV)

first shower seen by the four telescopes



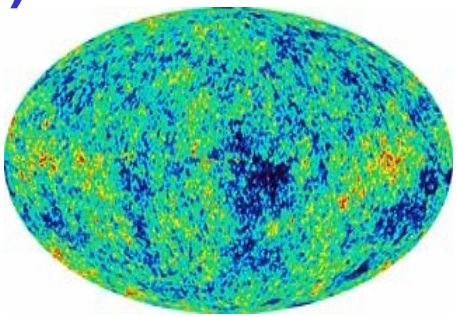
Energy calibrated using hybrid events

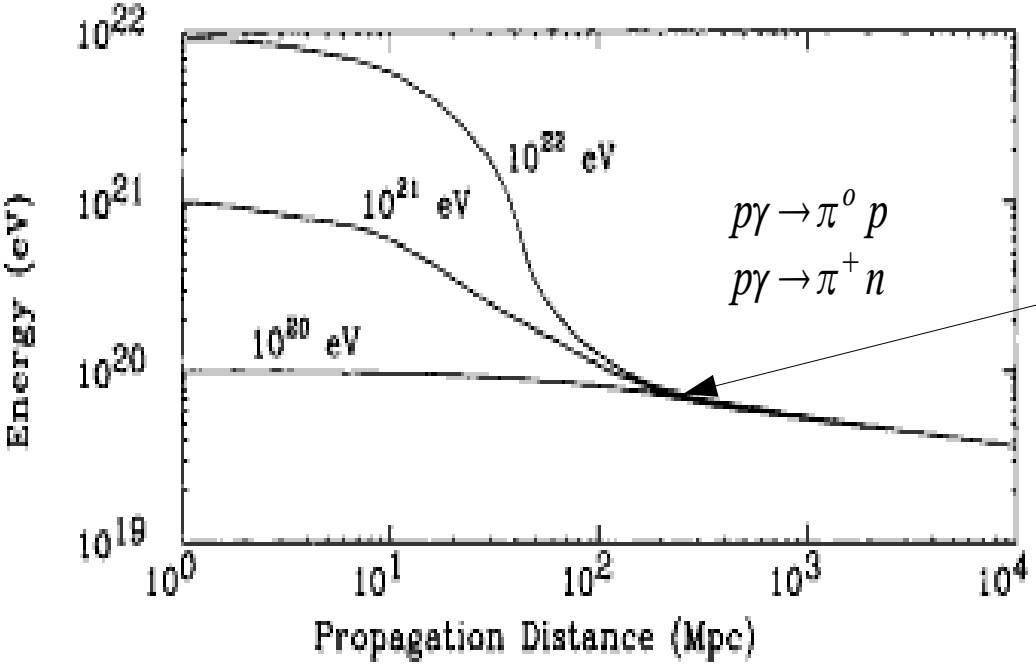


(attenuation in atmosphere accounted with Constant Intensity Cut method)

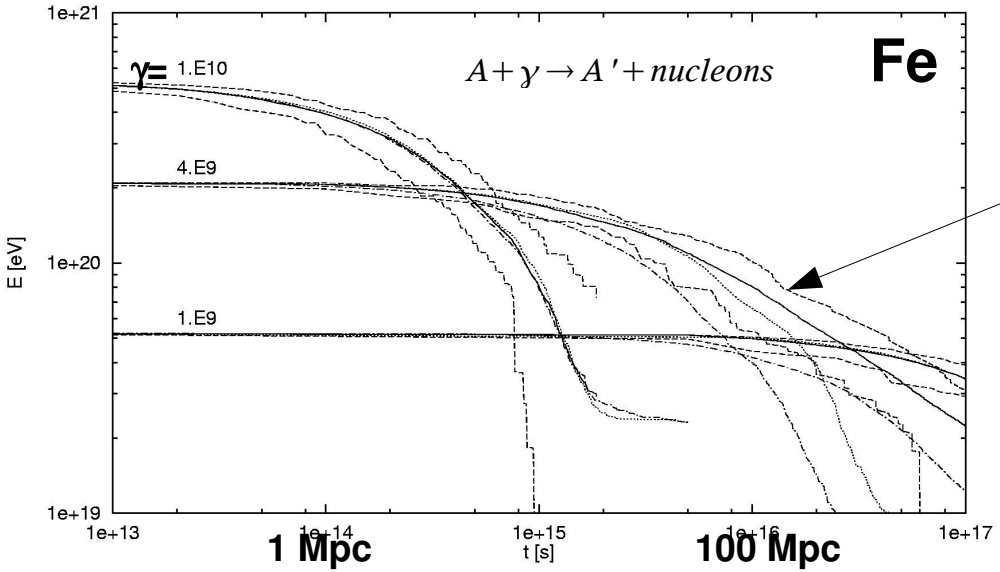
the Greisen-Zatsepin-Kuzmin effect (1967)

AT THE HIGHEST ENERGIES, PROTONS LOOSE ENERGY BY INTERACTIONS WITH THE CMB BACKGROUND





PROTONS CAN NOT ARRIVE WITH E > 6x10^{19} eV FROM D > 200 Mpc

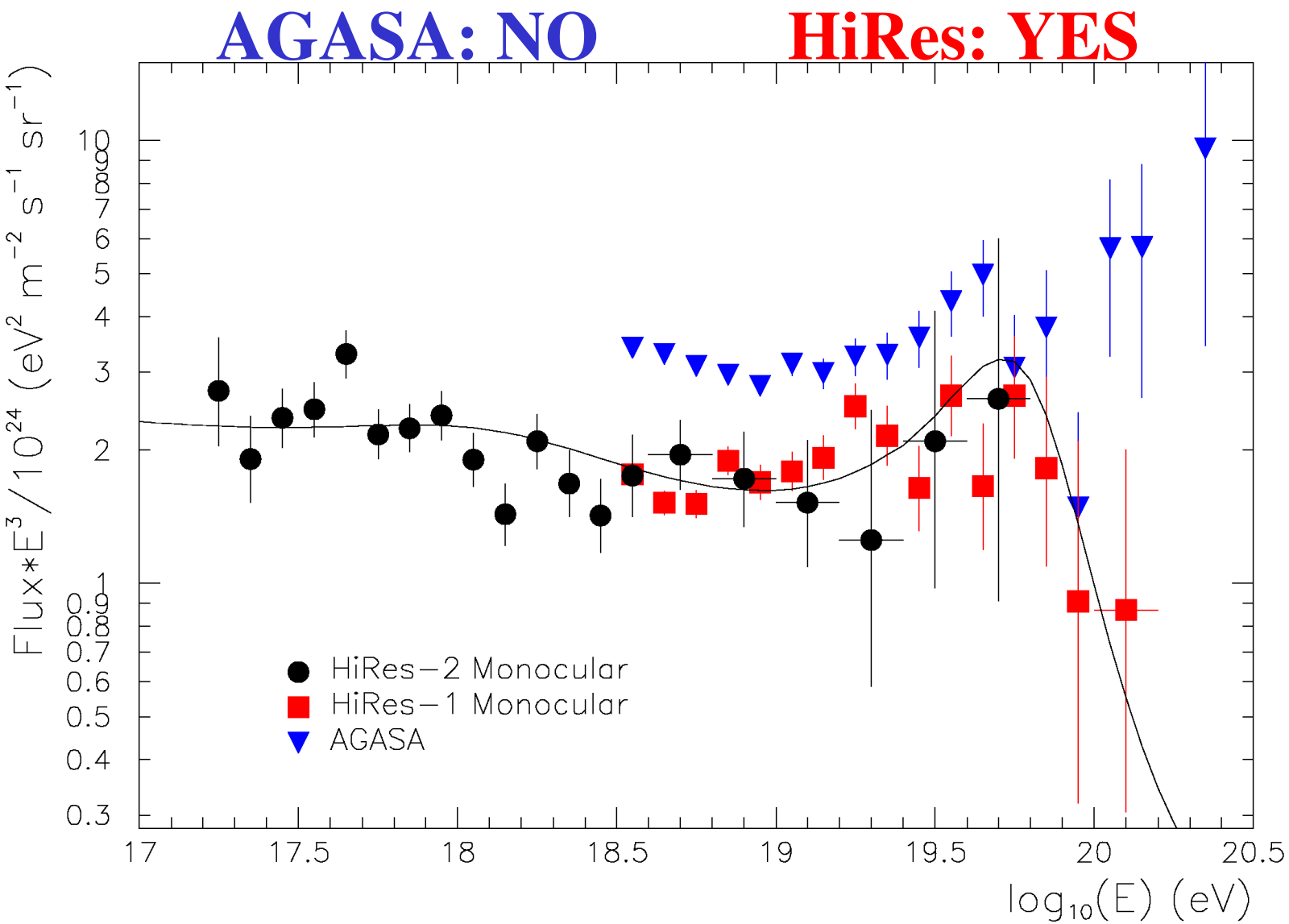


For Fe nuclei:
after ~ 200 Mpc the leading fragment has E < 6x10^{19} eV

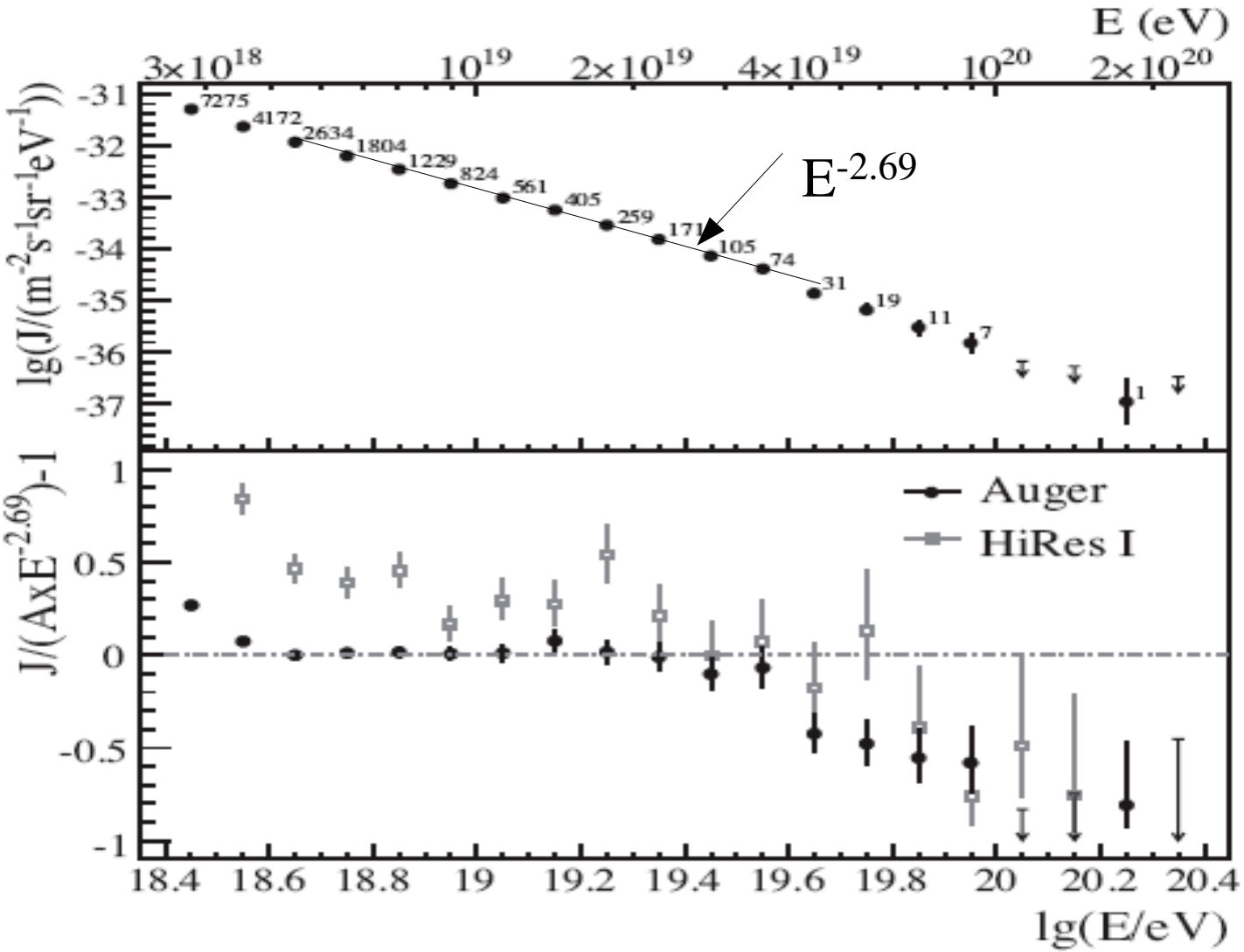
ligther nuclei get disintegrated on shorter distances

THE END OF THE SPECTRUM: GZK?

previous results



AUGER SPECTRUM FROM SD

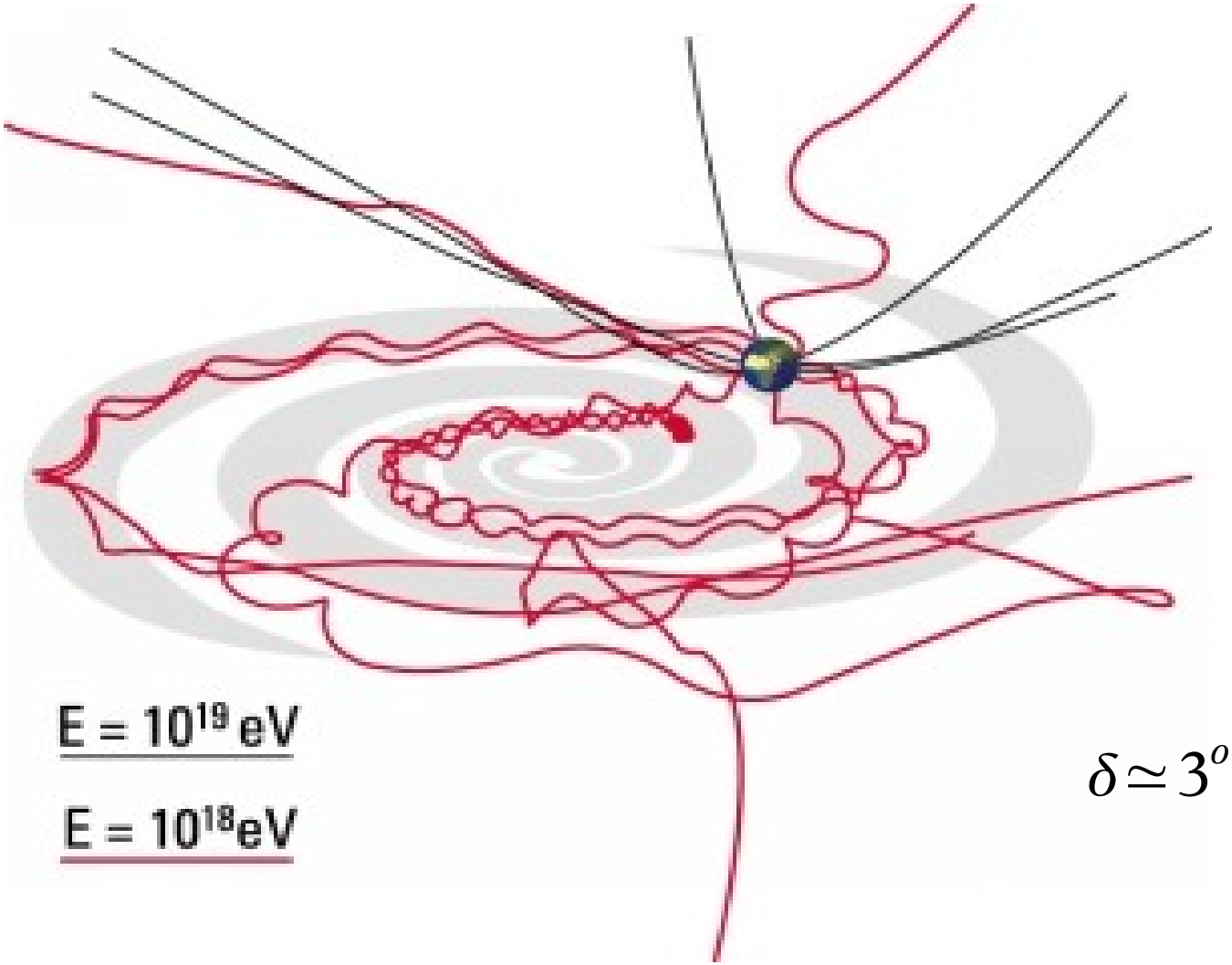


extrapolating $E^{-2.69}$ spectrum expect 167 events above 40 EeV → observe 69

Flux falls to half the extrapolated value for E ~ 6×10^{19} eV

GZK suppression has been observed (> 6σ)

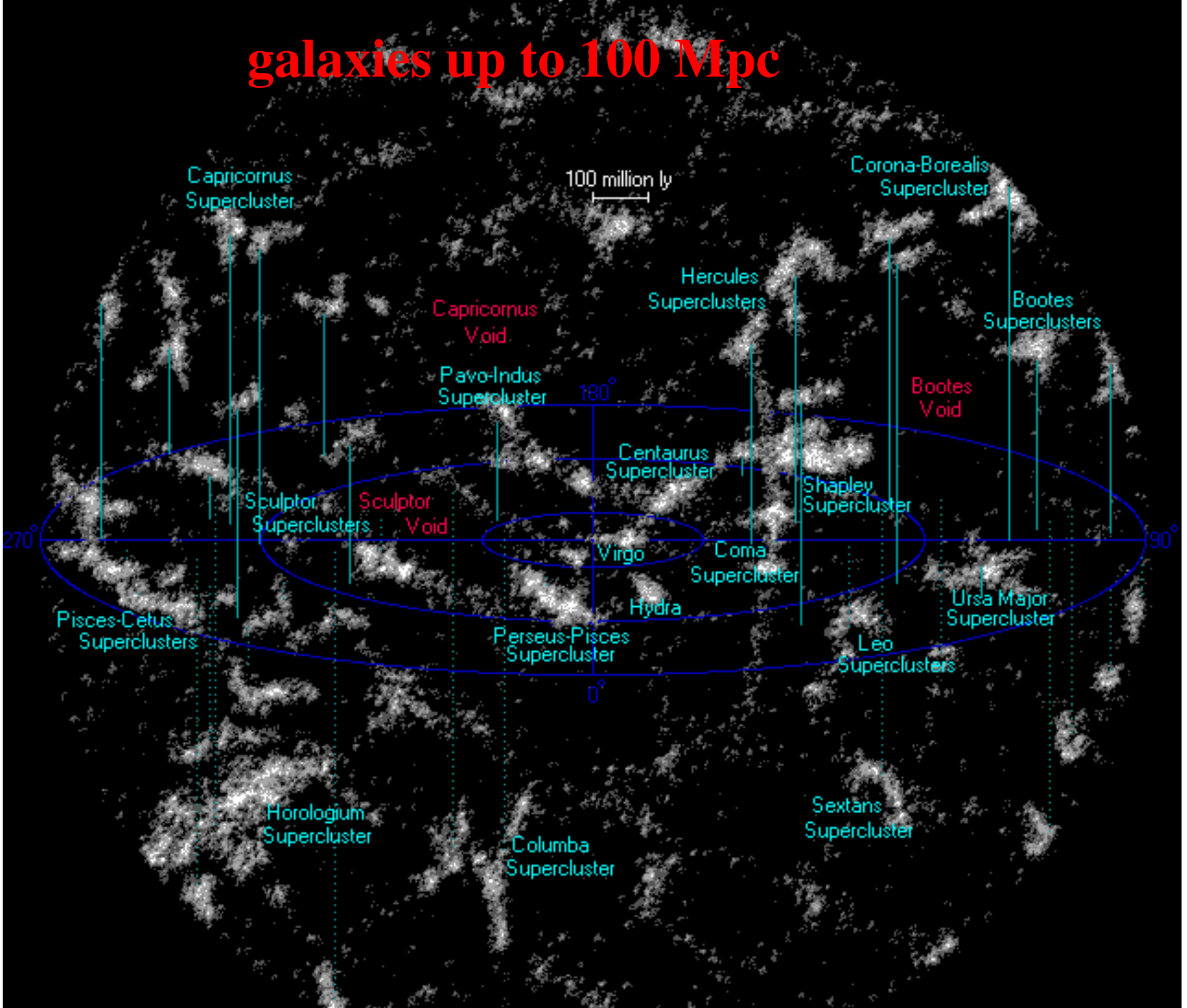
Cosmic Ray astronomy?



$$\delta \simeq 3^o \frac{B}{3\,\mu G} \frac{L}{kpc} \frac{6\times 10^{19} eV}{E/Z}$$

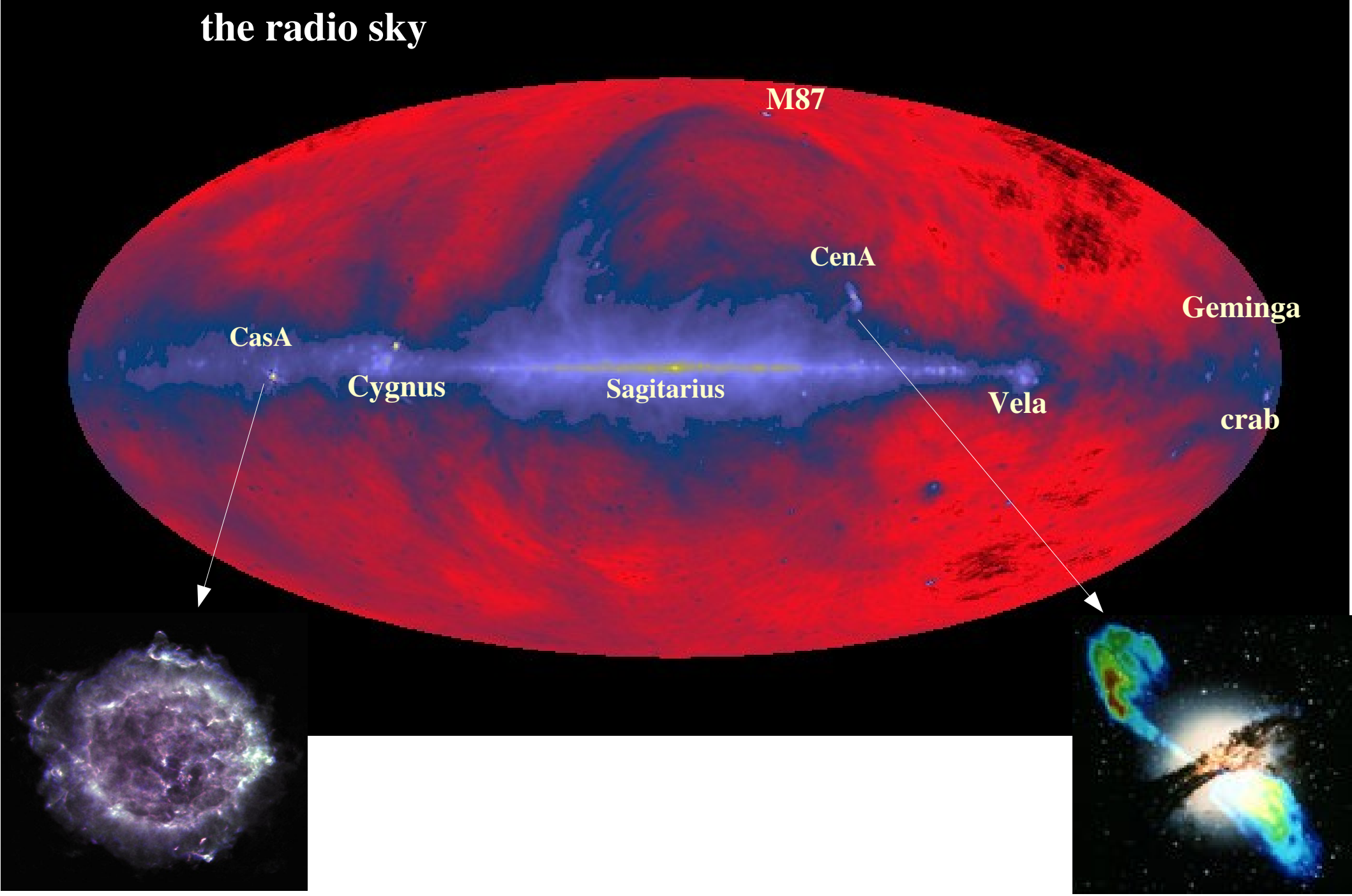
only for E/Z ≫ 10^{19} eV deflections in galactic magnetic fields become less than a few degrees and CR astronomy could become feasible

galaxies up to 100 Mpc



the nearby Universe is quite inhomogeneous

the radio sky

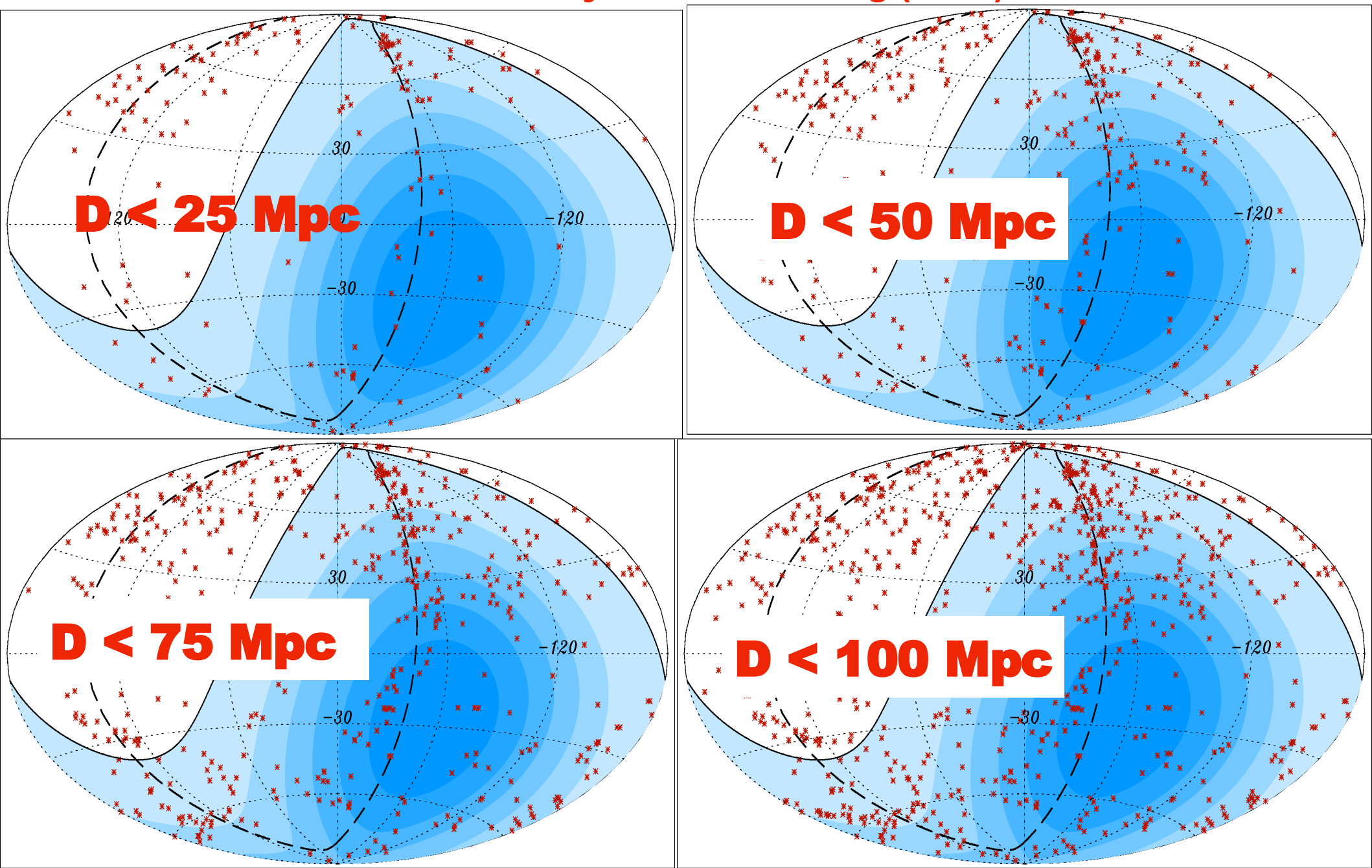


supernovae: preferred candidate sources for $E < 10^{18}$ eV

active galaxies: plausible candidates for $E > 10^{18}$ eV

NEARBY ACTIVE GALAXIES (AGN)

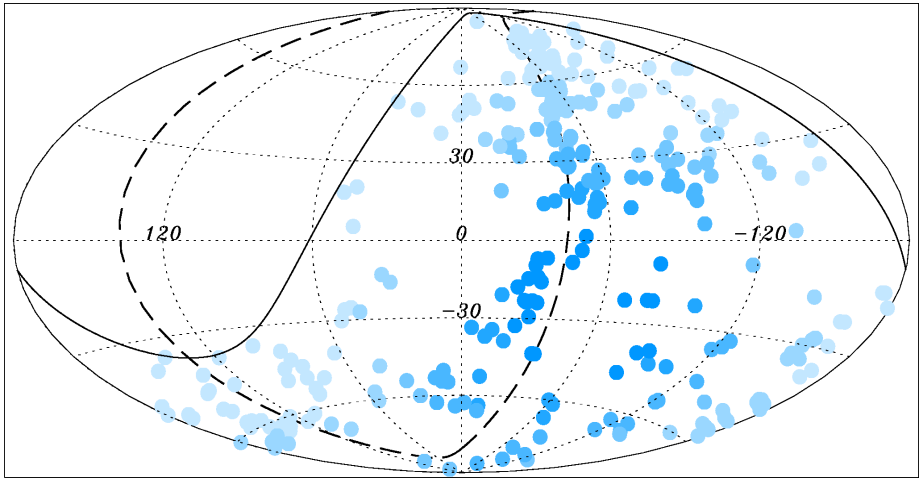
From the Véron-Cetty & Véron catalog (2006)



SEARCH FOR CORRELATIONS WITH NEARBY AGN

Let p be probability that a CR from an isotropic flux arrives with angular separation smaller than ψ from an AGN at a distance smaller than D_{max}

(= Fraction of the area, weighted by the exposure, covered by circular windows of radius ψ)



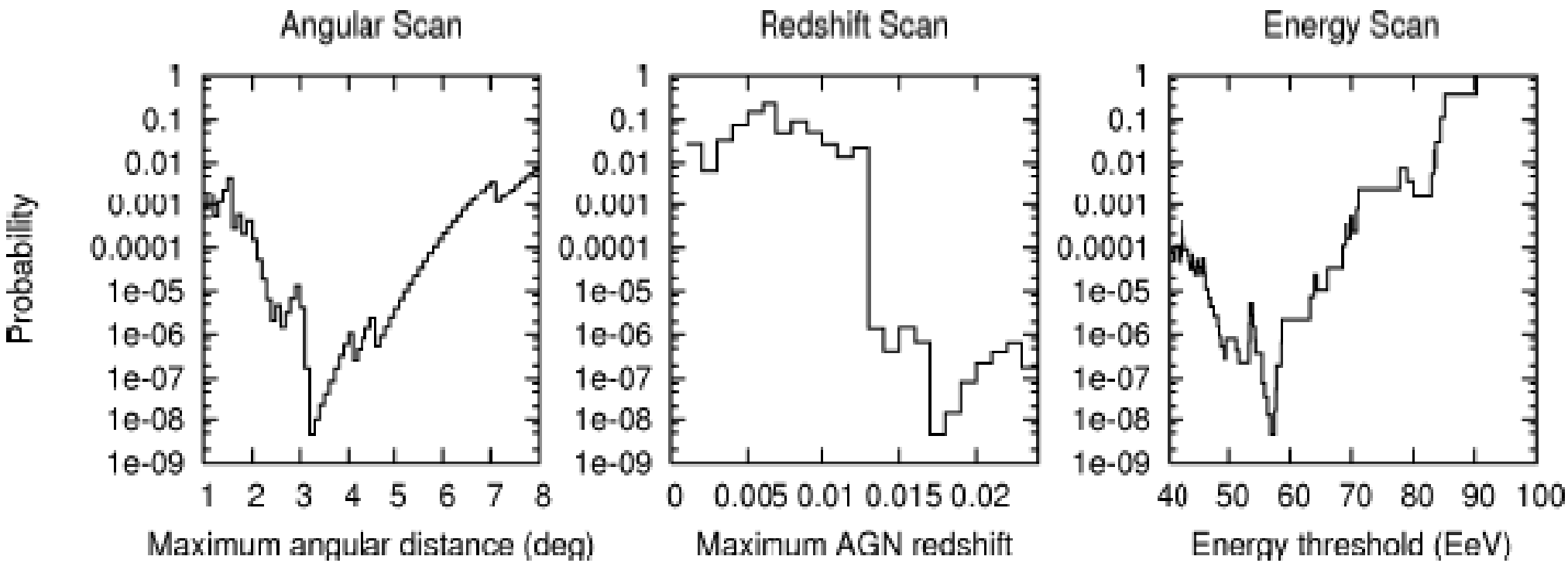
e.g. p = 0.21 for D_{max} = 75 Mpc , ψ = 3.1°

if for the n highest E events ($E > E_{min}$) there are k correlations in the data the probability to find an isotropic realisation more correlated than the data is:

$$P = \sum_{j=k}^{n} \binom{n}{j} p^j (1-p)^{n-j}$$

Minimize P scanning over ψ (deflection), D_{max} (GZK horizon) and E_{min} (Number of highest E events considered)

Minimum of P: $E_{min} \sim 6 \times 10^{19}$ eV (n = 27) $\psi \sim 3^o$ D ~ 75 Mpc



$f \sim 10^{-5}$ fraction of isotropic simulations of 81 events (E>40 EeV) which have a smaller P_{min} under the same scan

HISTORICAL NOTE

Data analysed from Jan 2004 up to 26 May 2006

First hints of correlations obtained through this scan

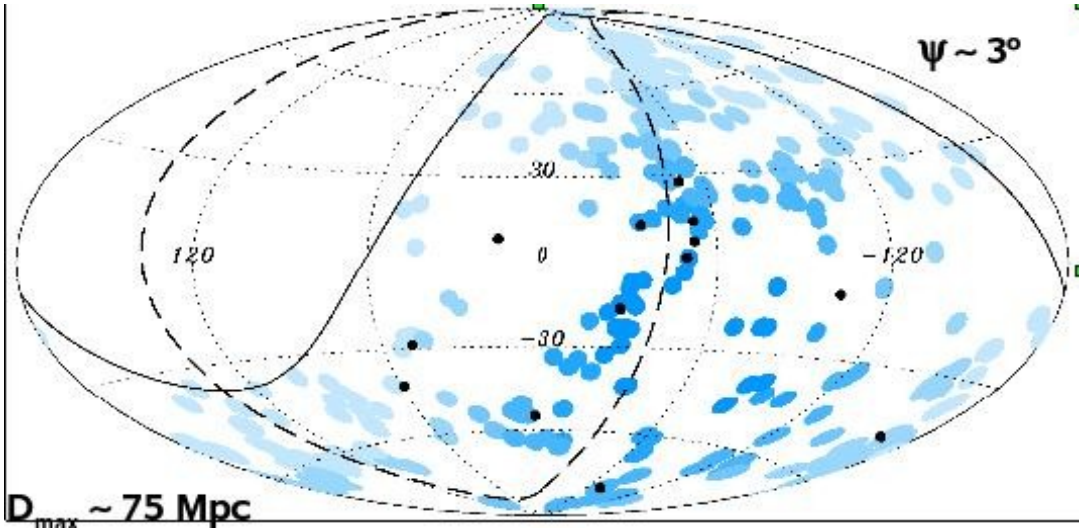
12/15 correlations

(3 expected)

D_{max} = 75 Mpc $\psi = 3.1^o$

$E_{min} = 5.6 \times 10^{19}$ eV

$f \sim 10^{-3}$

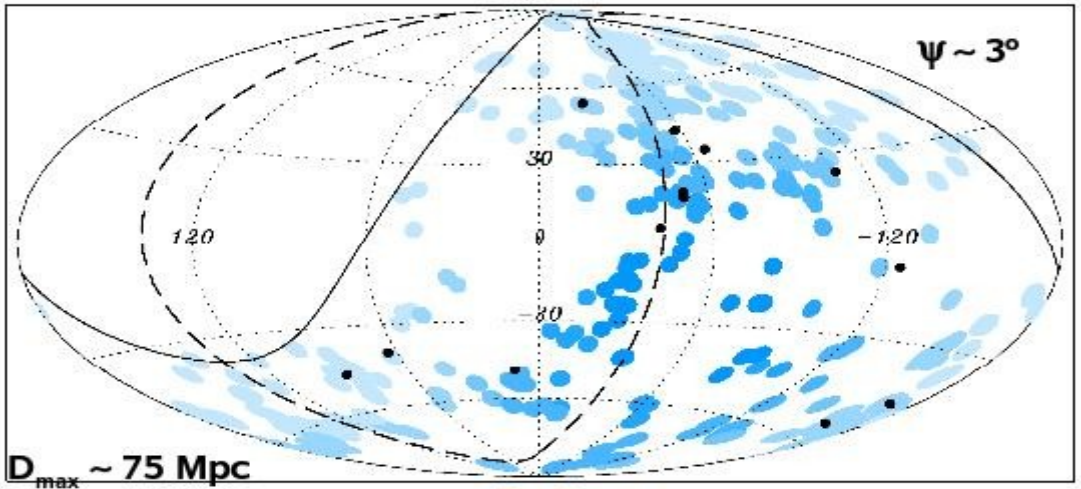


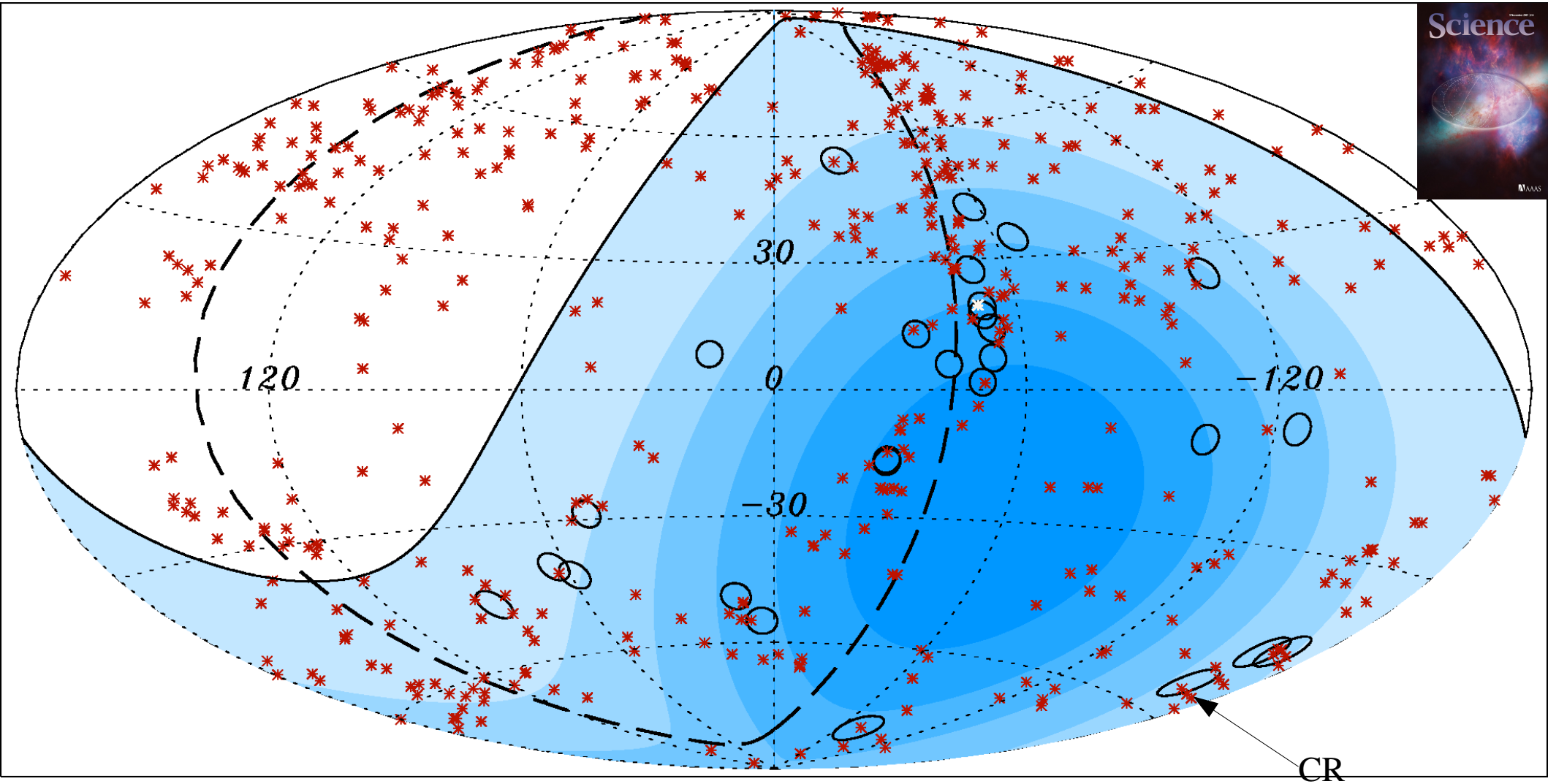
Test with parameters fixed a priori

Data analysed from 27 May 2006 up to 31 Aug 2007

8/13 correlations

in this independent set with parameters specified apriori the probability that flux be isotropic is < 1%



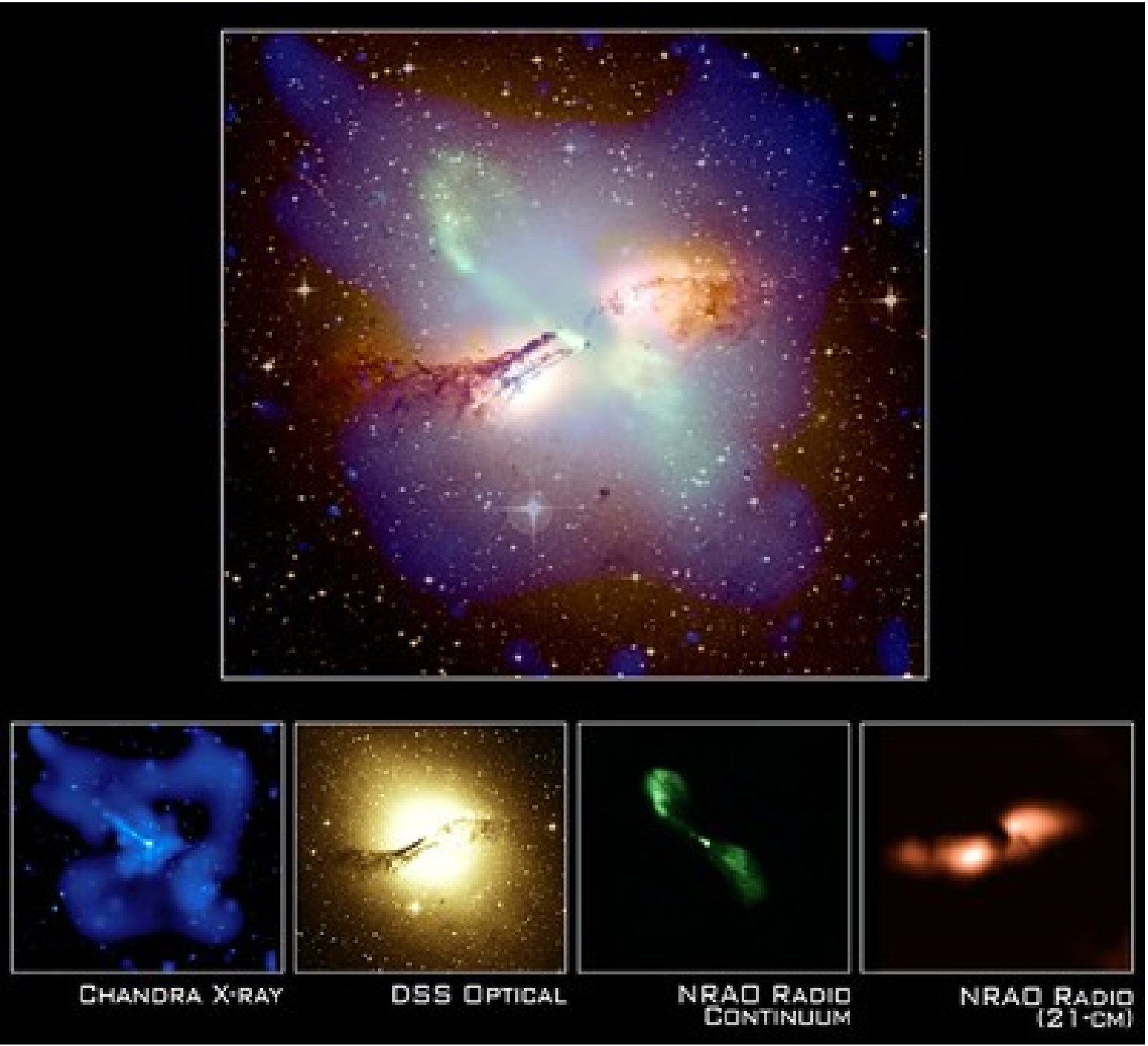


with the data up to 31 august 2007, from the 27 CRs with highest energies, 20 are at less than ~3 degrees from an active galaxy at less than ~ 75 Mpc , while 6 were expected

(from the 7 which are not, 5 have $|b_G| < 12$ deg, where catalog is largely incomplete)

Closest Active galaxy: Centaurus A

(~ 3 Mpc)



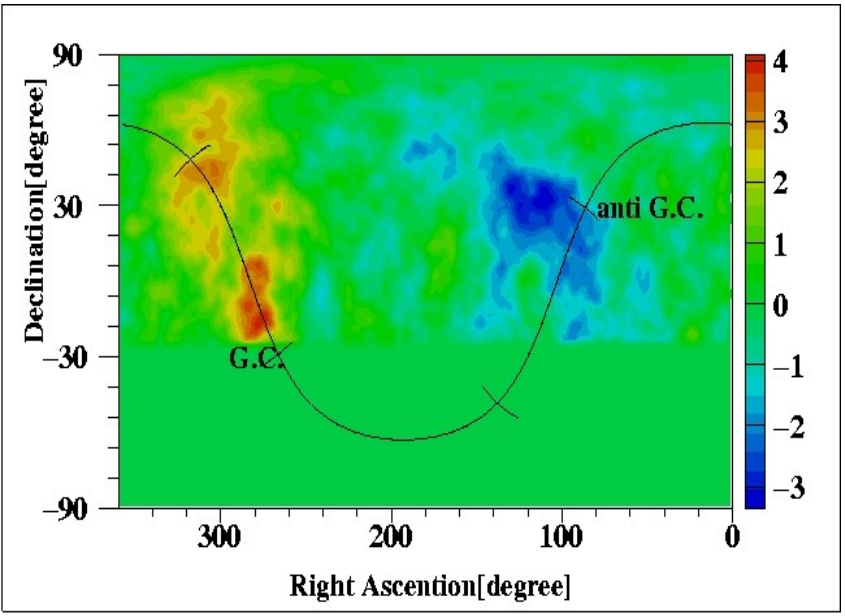
2 events at less than 3 deg from it

central black hole with more than 100 million solar masses !

collision of 2 galaxies

relativistic jet

AGASA ANISOTROPIES ON 20º SCALES (10^{18} – $10^{18.4}$ eV)



$$\frac{observed}{expected} = \frac{506}{413.6} \quad (+4.5\sigma) \quad \textbf{at} \quad (\delta, \alpha) = (-15, 280)$$

(22% excess)

AUGER got $\frac{observed}{expected} = \frac{2116}{2159.6} \quad (-1\sigma)$

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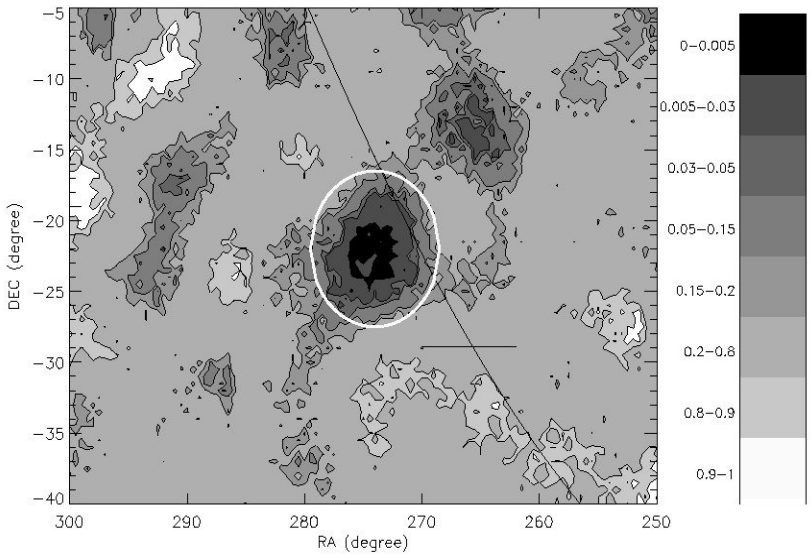
SUGAR galactic center search (5.5º for $10^{17.9}$ – $10^{18.5}$ eV)

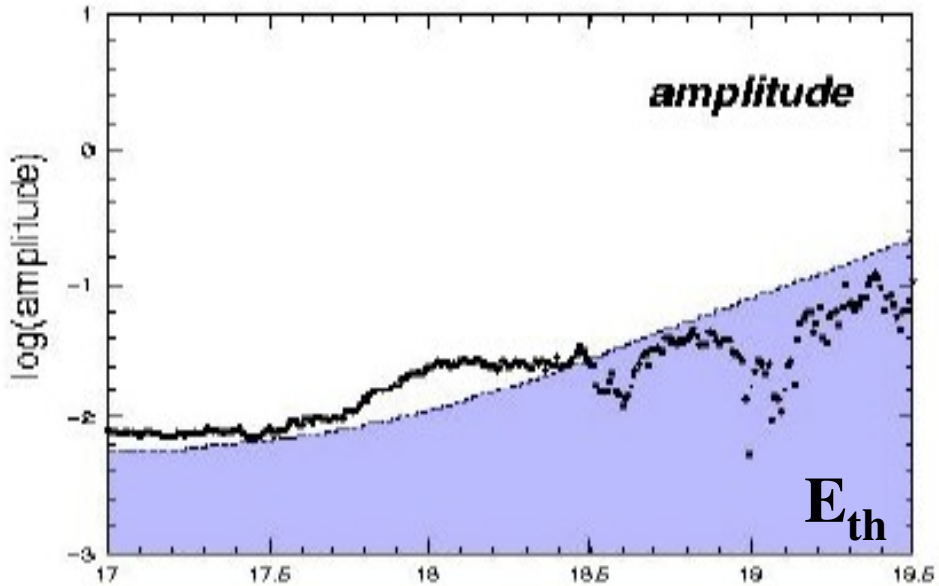


$$\frac{observed}{expected} = \frac{21.8}{11.8} \quad (+2.9\sigma) \quad \textbf{at} \quad (\delta, \alpha) = (-22, 274)$$

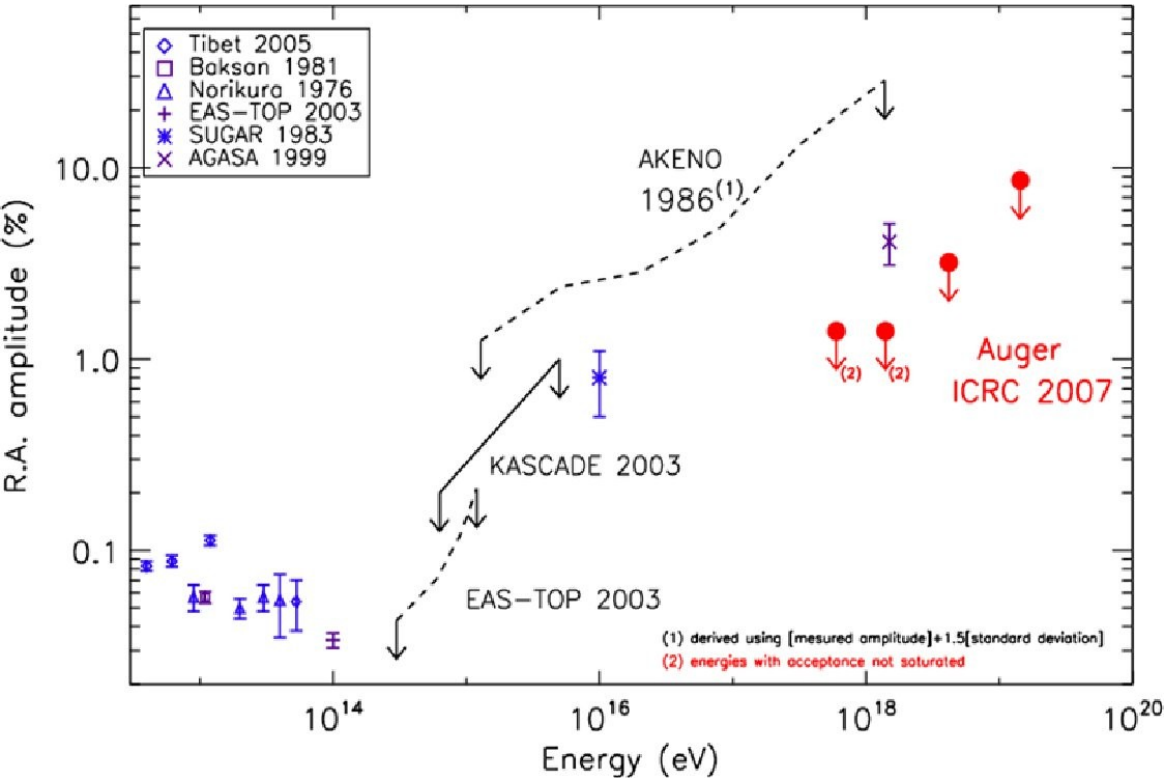
(85% excess)

AUGER got $\frac{observed}{expected} = \frac{286}{289.7} \quad (-0.3\sigma)$

AGASA RAYLEIGH ANALYSIS vs. E

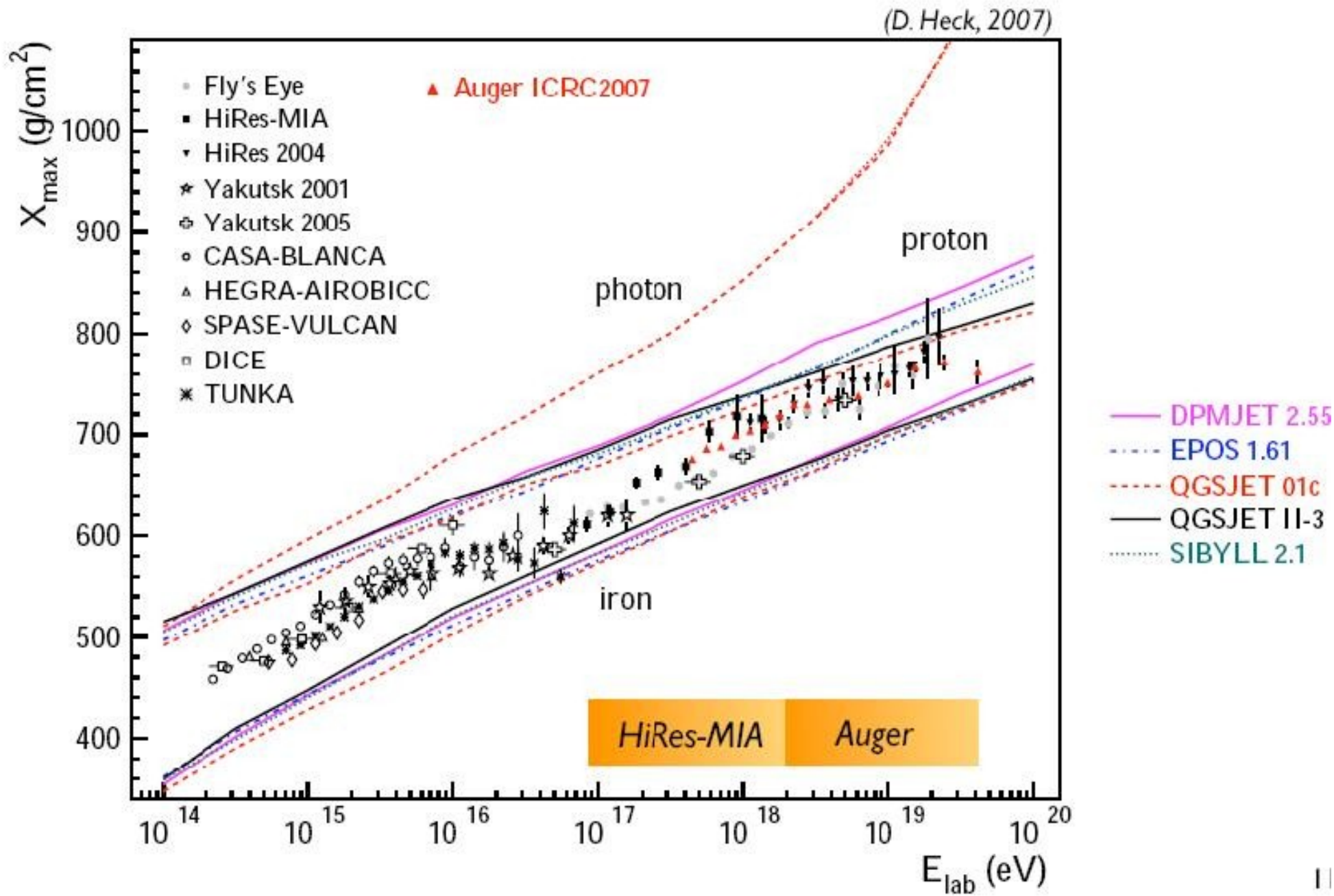


4 % amplitude of 'dipolar' modulation for E > 1 EeV



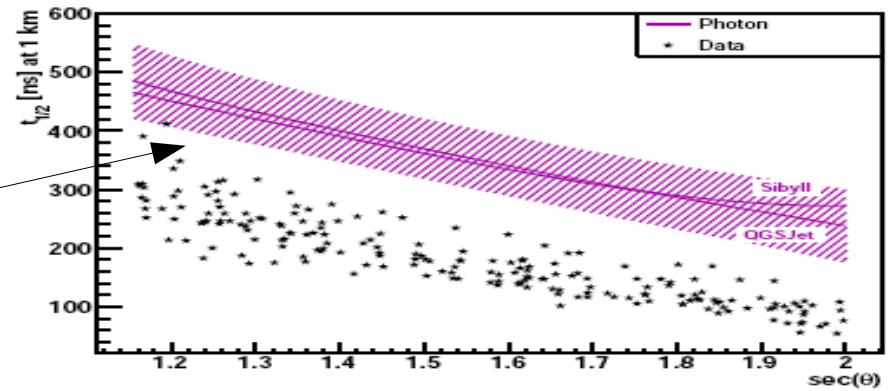
Auger bound:
amplitude < 1.4% for [1,3] EeV

COMPOSITION FROM X_{max}

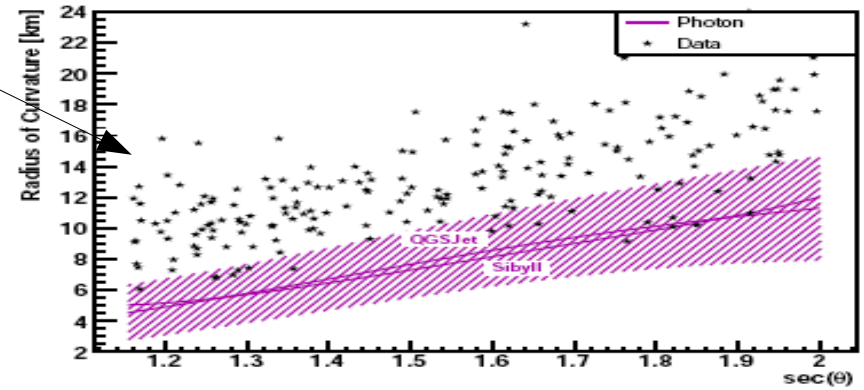


AUGER SD photon bound

photon showers mostly electromagnetic: long rise times



and develop later → small curvature radius (and large X_{max} in FD)



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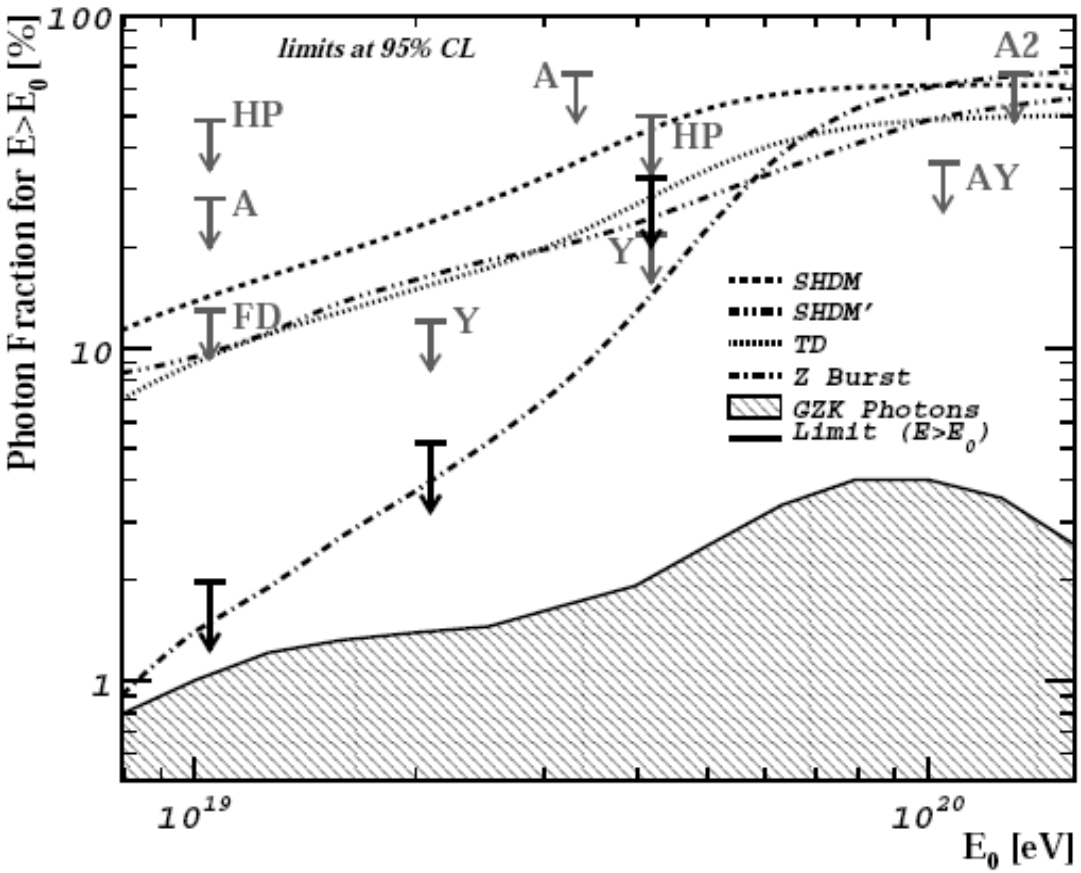


photon fraction:

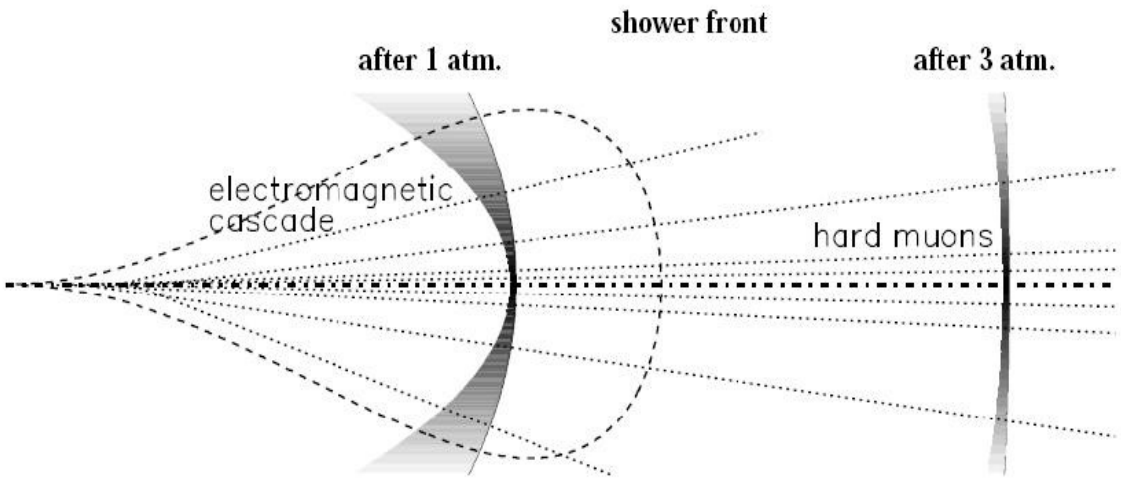
< 2% at E > 10 EeV

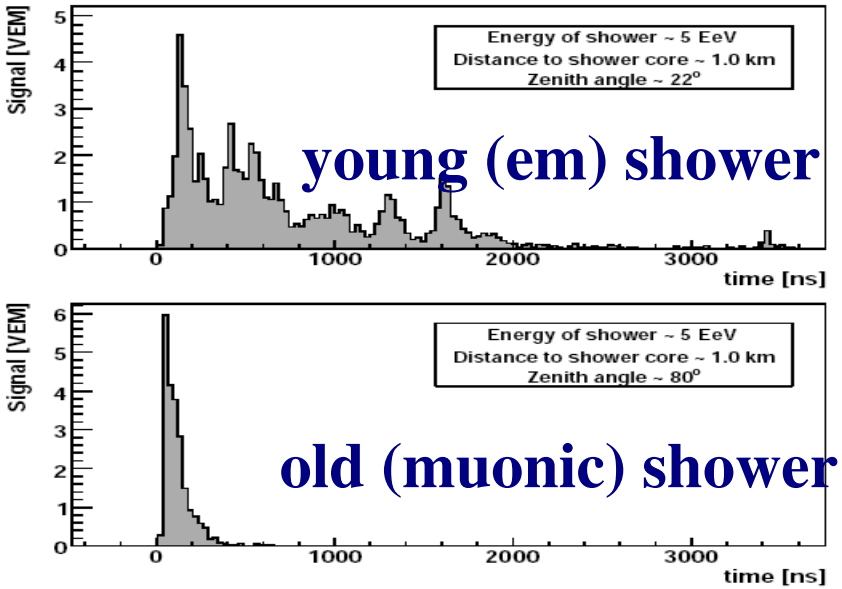
< 31% at E > 40 EeV

excludes most top-down models

AUGER BOUNDS ON DIFFUSE NEUTRINO FLUX

unlike hadronic CRs, neutrinos can produce young horizontal showers above the detector, and upcoming near horizontal tau lepton induced showers





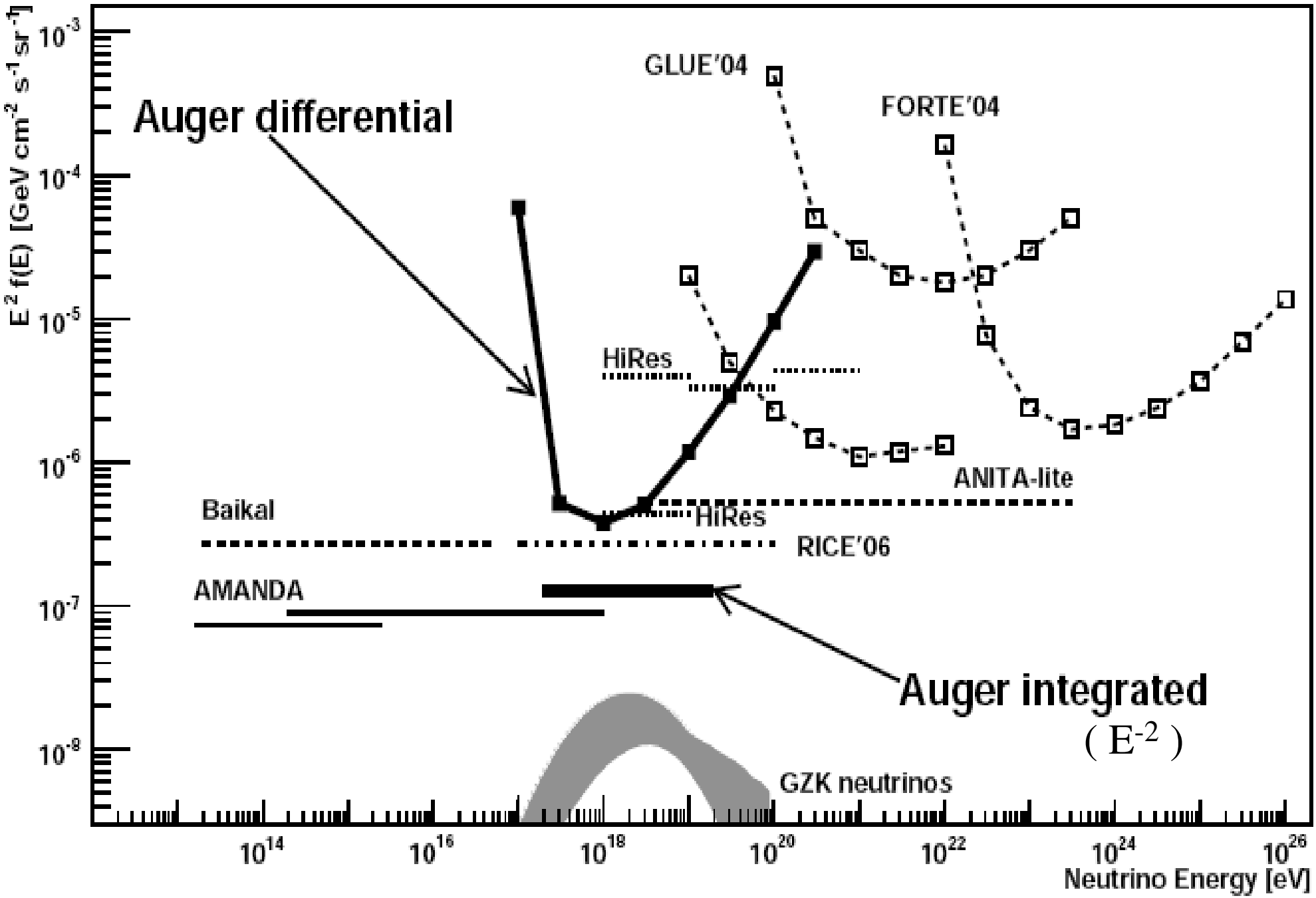
Horizontal young showers?

60% of tank signals with large Area / peak

Elongated tracks: L/W > 5 Propagation with v ~ c

ZERO CANDIDATES

bound from Earth skimming ν_τ (PRL 08)



CONCLUSIONS

Observatory construction almost accomplished

Data analysed ~ 1 yr of data expected in completed Observatory

Evidence that CRs are attenuated by GZK effect

CRs arriving to Earth with $E > 6 \times 10^{19}$ eV are extragalactic

Sources preferentially in regions at less than ~ 100 Mpc in which Active Galactic Nuclei are present
(if other than AGN, sources must have a similar spatial distribution)

photon fraction small (< 2% above 10 EeV)

no neutrinos yet

the charged particle astronomy is being born

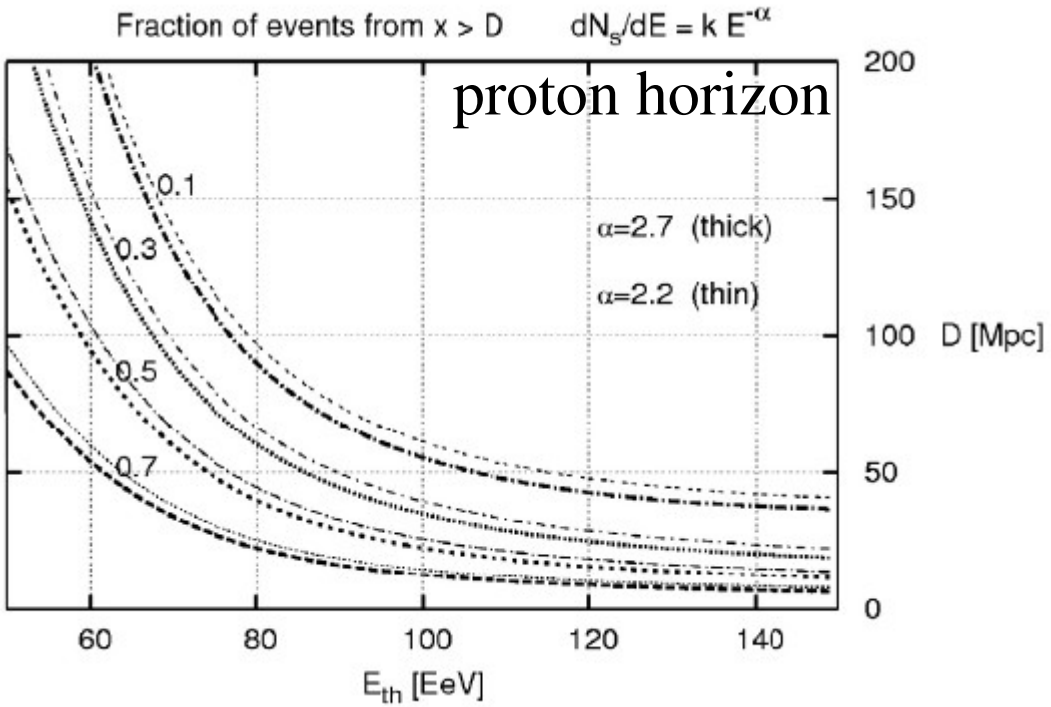
providing a new window to observe the Universe

this will allow to study the most violent processes in the Universe, understand the nature of the highest energy cosmic rays,
determine magnetic fields,
and answer many old questions .....


Where did it all come from?


Where did it all come from?
S. Harris

GZK HORIZON



if CRs are protons:

for E > 6x10^{19} eV

90% from D < 200 Mpc

50% from D < 100 Mpc

for E > 8x10^{19} eV

90% from D < 100 Mpc

50% from D < 40 Mpc