PIERRE AUGER OBSERVATORY

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SEARCH FOR NEARBY EXTRAGALACTIC SOURCES OF THE HIGHEST ENERGY COSMIC RAYS

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Centro Atómico Bariloche – Instituto Balseiro

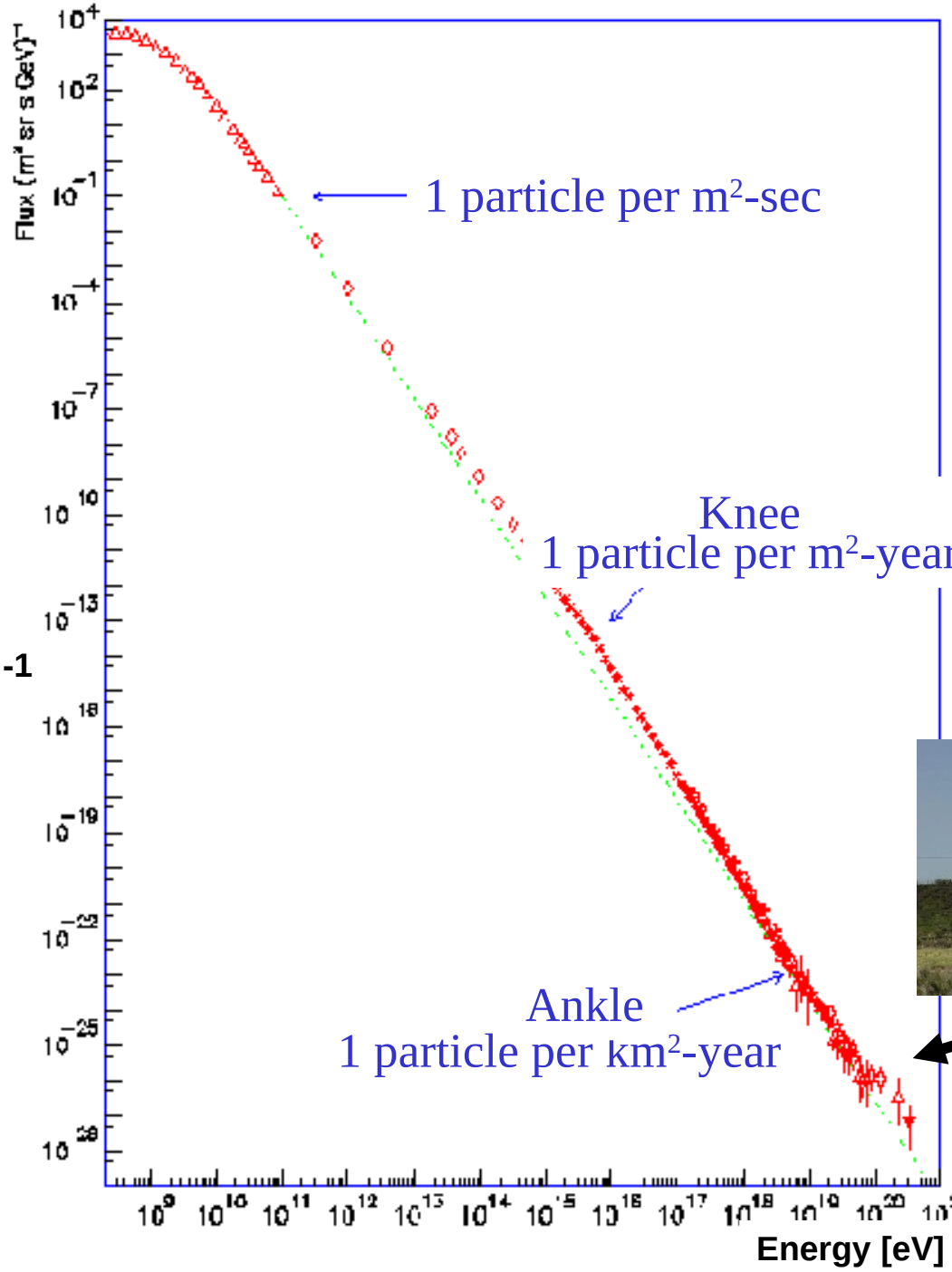
HEPRO II Buenos Aires, 27 October 2009

Summmary of recent measurements of

ENERGY SPECTRUM
COMPOSITION
ANISOTROPIES

FLUX OF COSMIC RAYS

$(m^2\ sec\ sr\ GeV)^{-1}$



AUGER

1 particle / km² - century

(E > 6 x 10^{19} eV)

POTENTIAL ACCELERATION SITES

Very special astrophysical conditions required

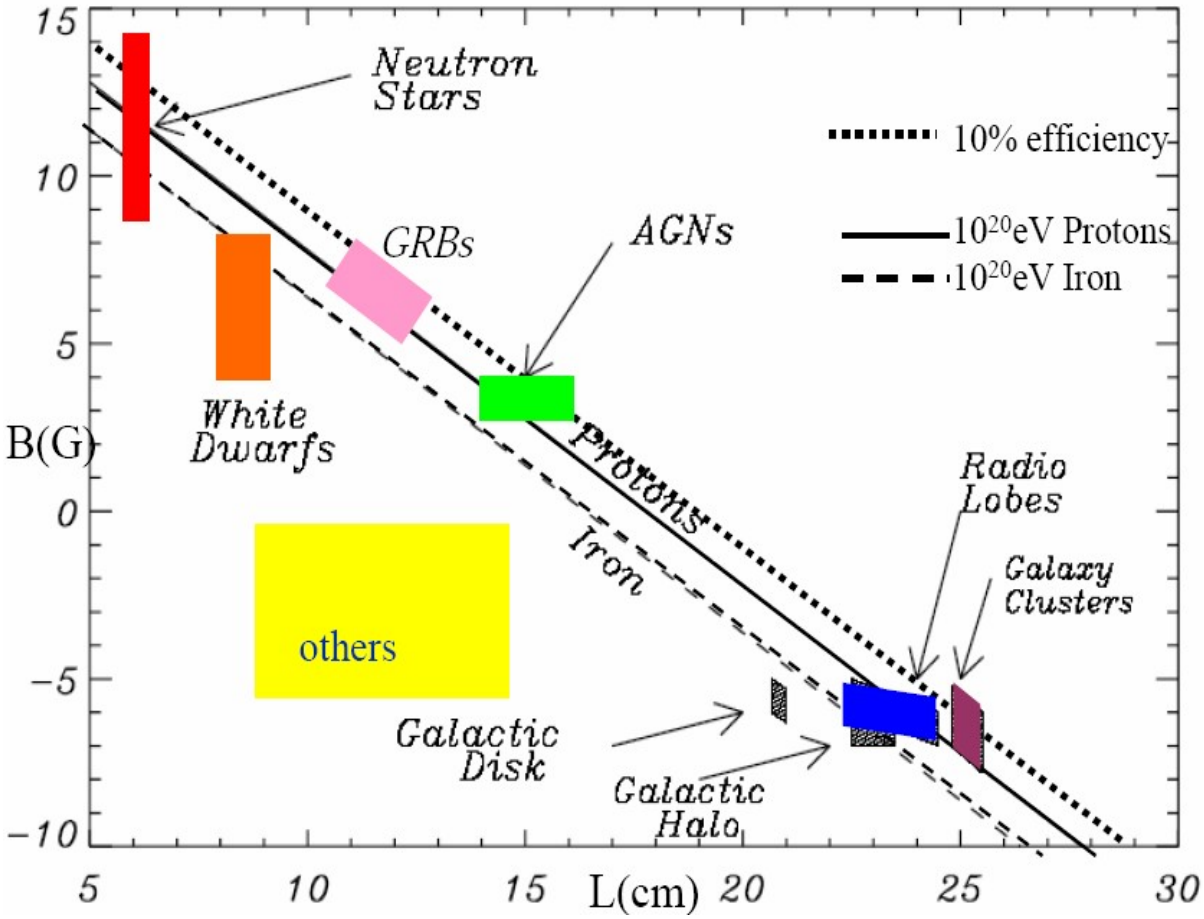
$E_{max}=10^{18}$ eV Z (B/μG) (L/Kpc)

ACTIVE GALAXIES

GAMMA RAY BURSTS

RADIOGALAXIES

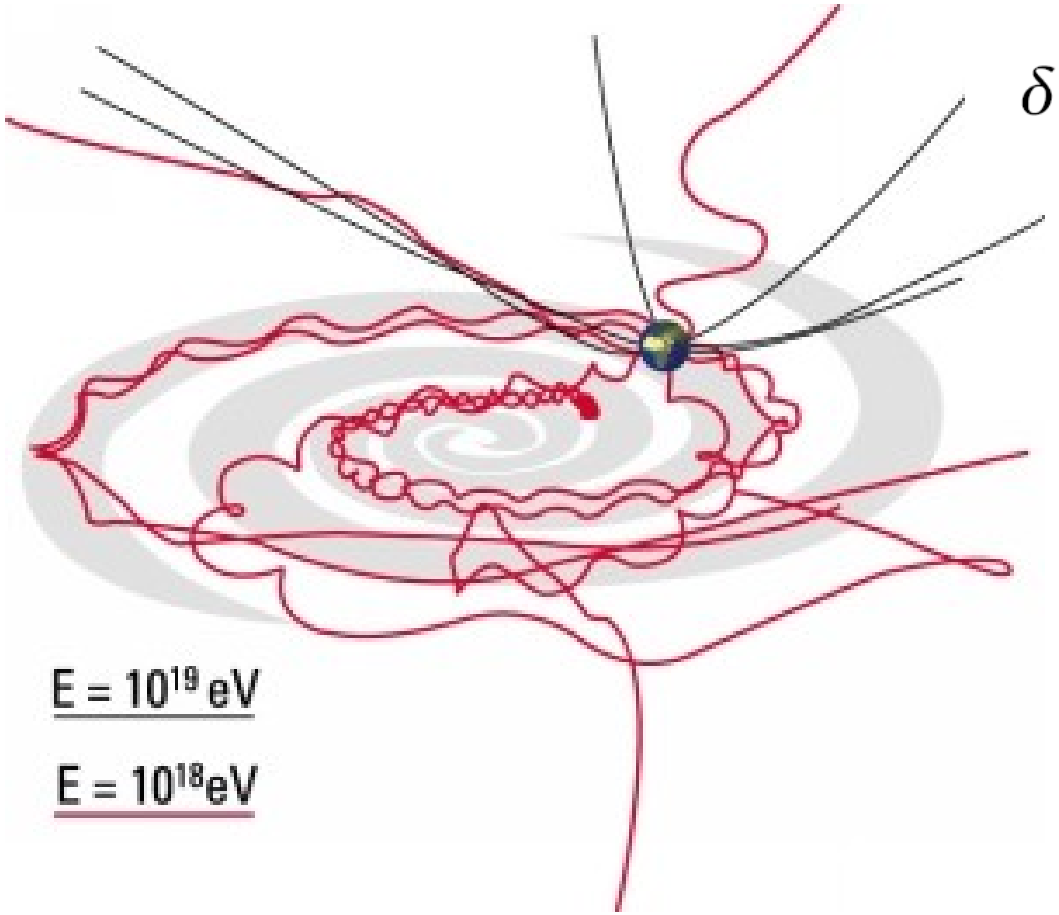
.....?



Hillas Plot

Highest energies required to attempt

ASTRONOMY WITH CHARGED PARTICLES



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

Galactic magnetic field deflects trajectories

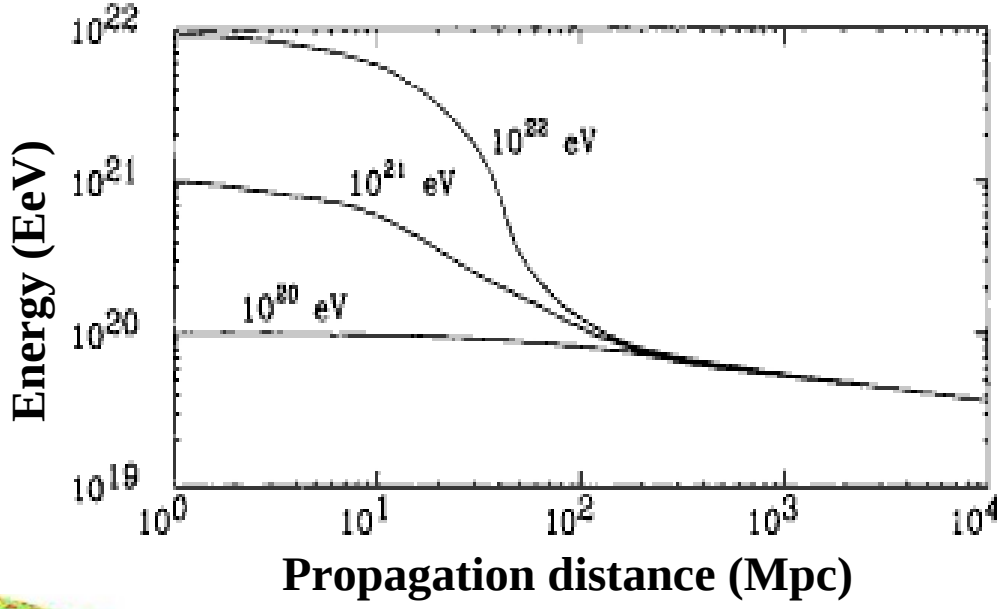
Expect a few degrees for protons with E ~10^{20} eV

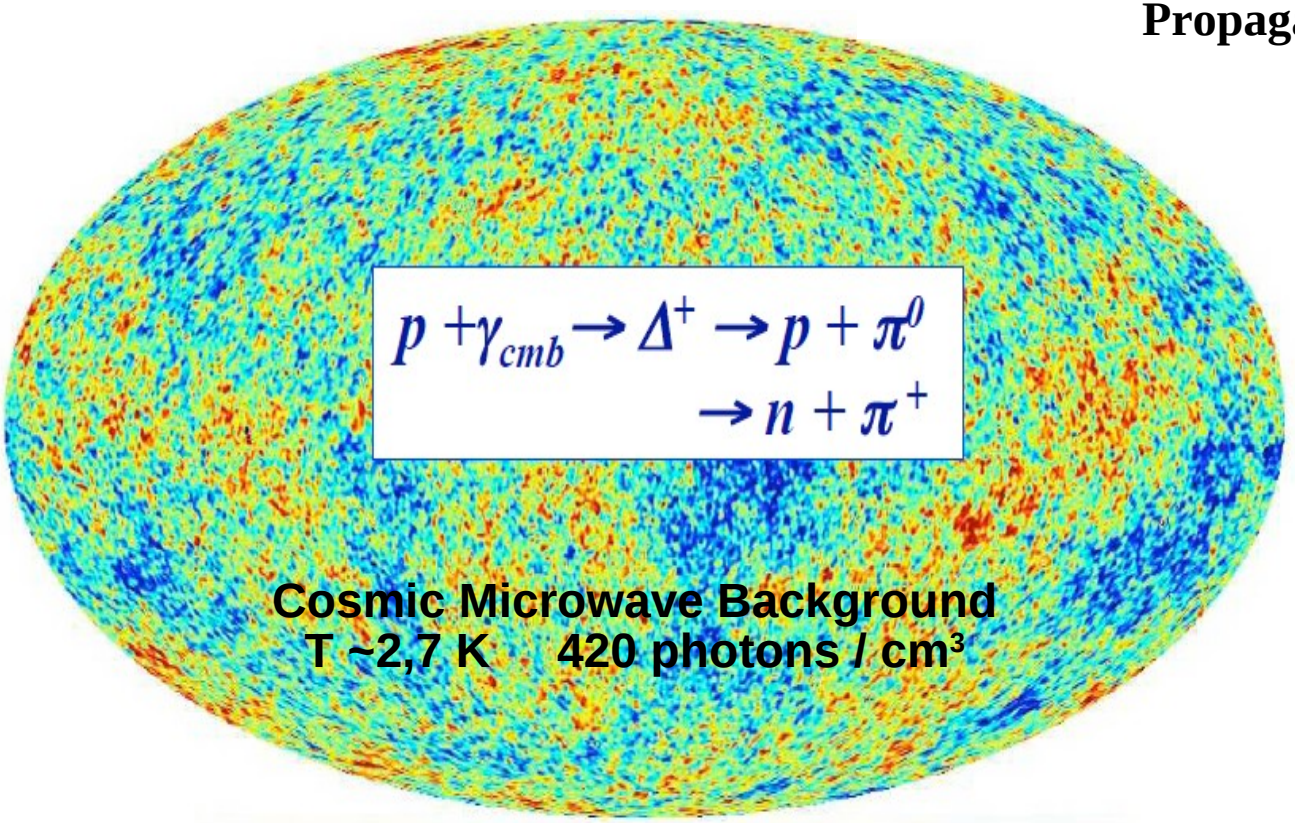
¿Are deflections small enough to identify individual sources?

GZK HORIZON:

sources should be nearby

(Greisen-Zatsepin-Kuzmin 1966)

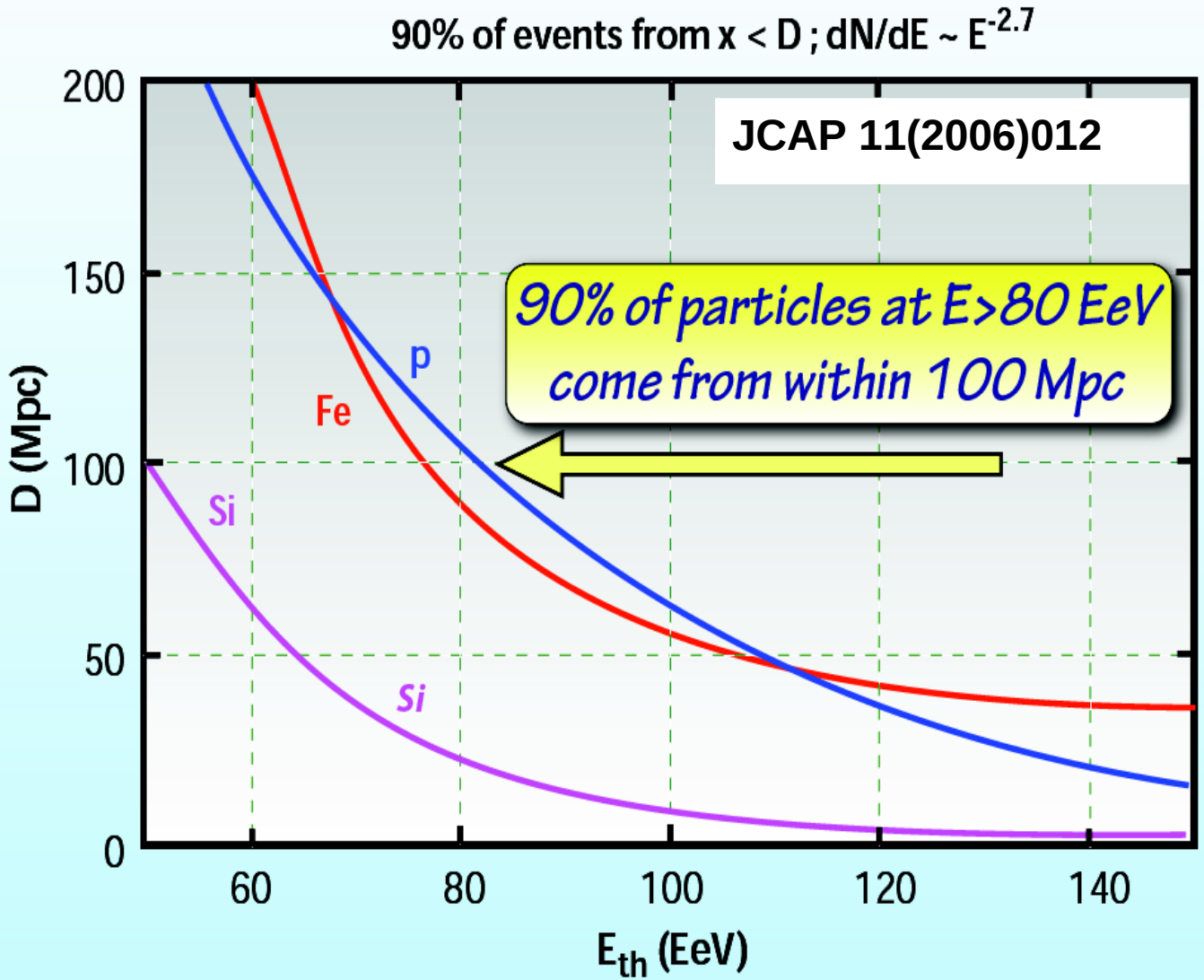




Cosmic Microwave Background
T ~2,7 K 420 photons / cm³

UHECR HORIZON:

CRs THAT ARRIVE ON EARTH WITH
$E > 6 \times 10^{19}$ eV
COME FROM D < 200 Mpc

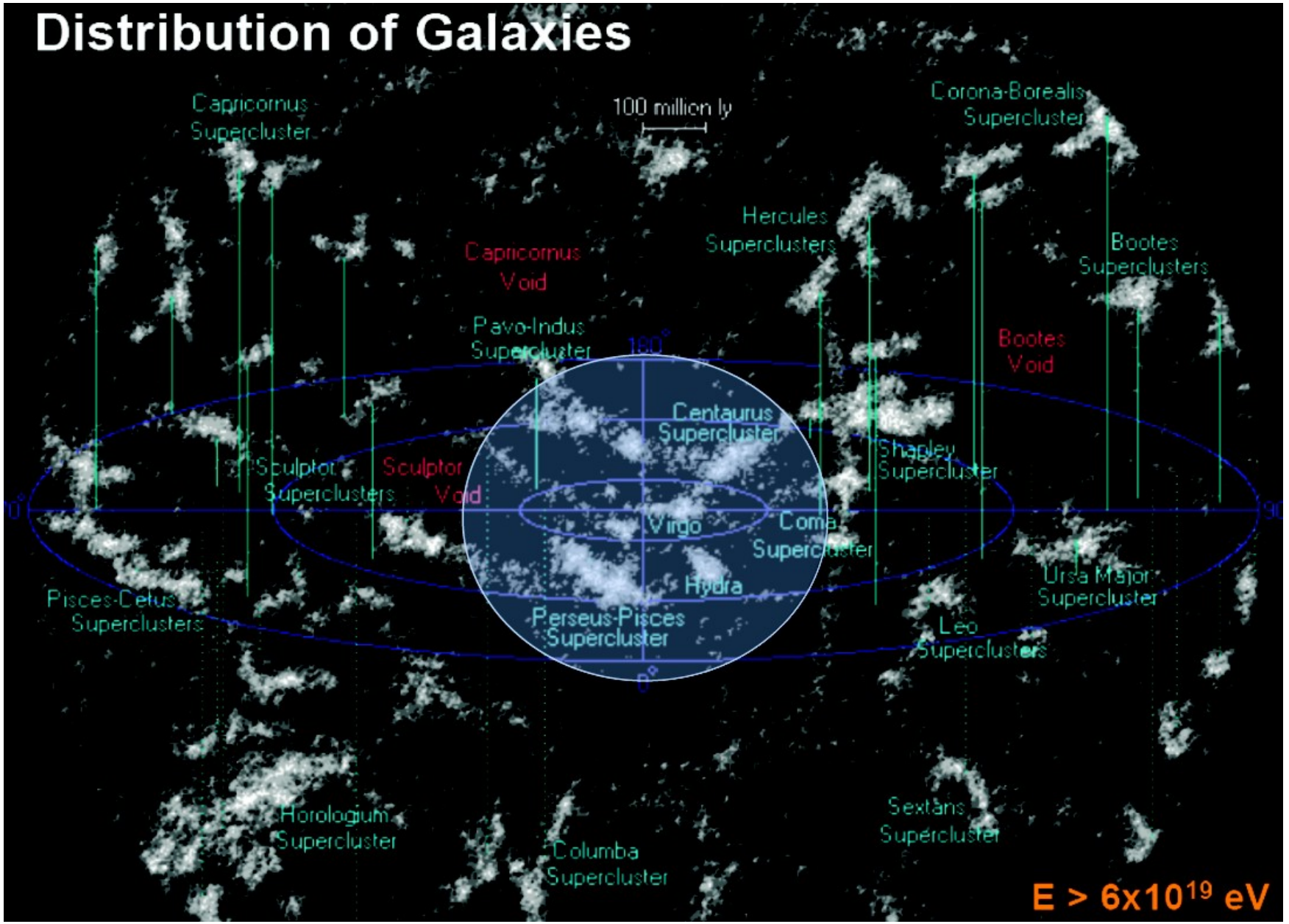


Even smaller horizon for intermediate-mass nuclei (photodisintegration)

Expect:

Flux suppression

Nearby sources

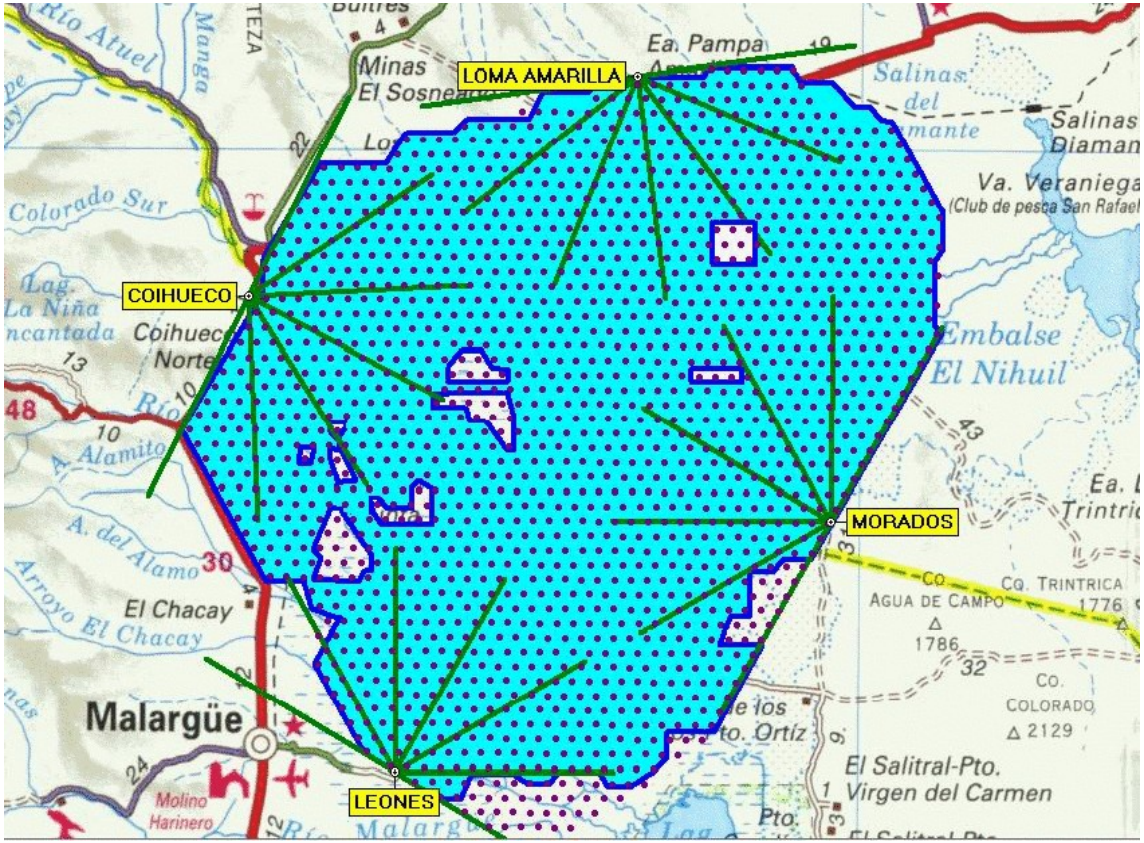


GZK HORIZON: **Nearby sources** **Flux suppression**

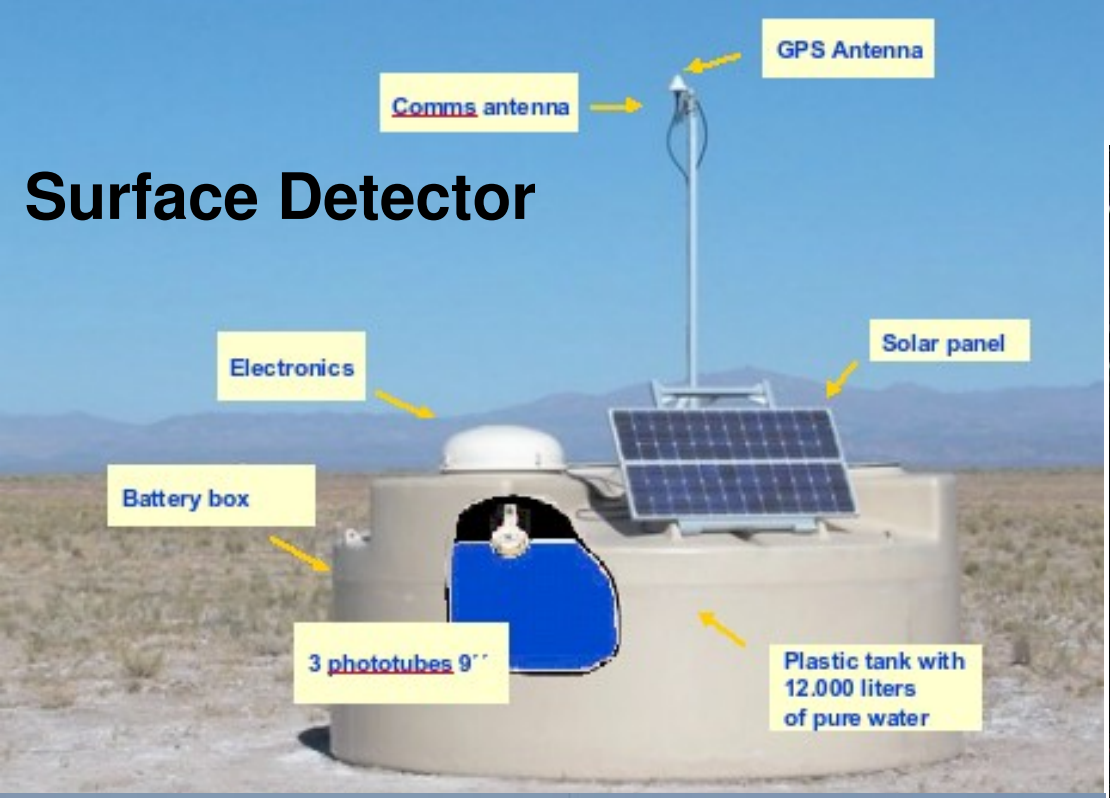
Pierre Auger Observatory

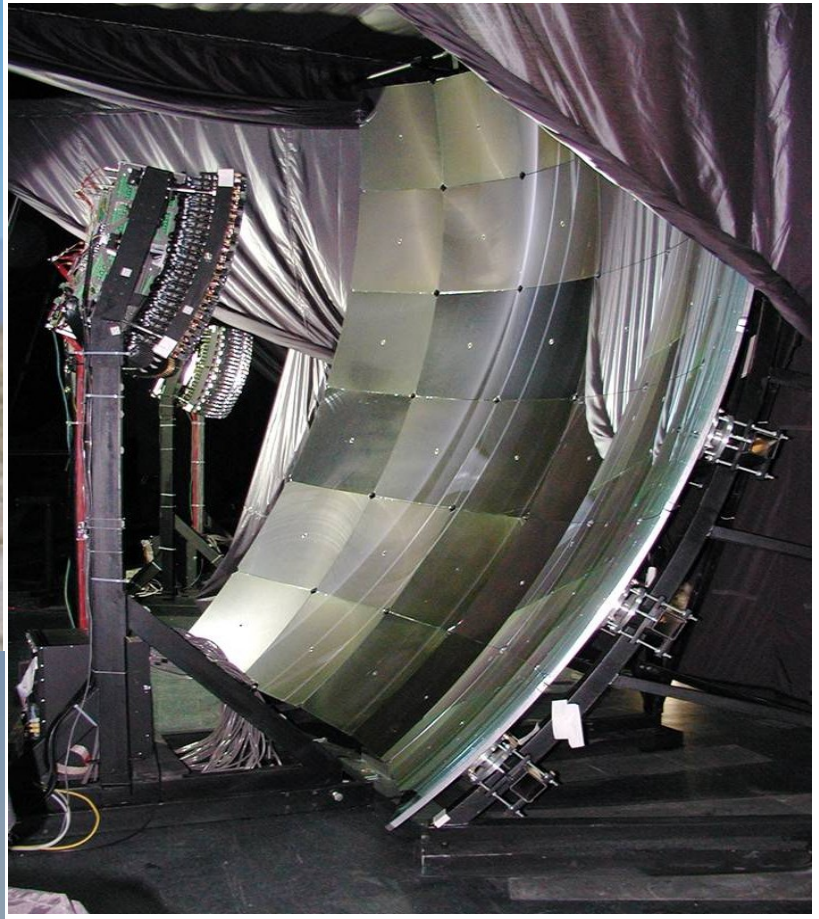
few cosmic rays at the highest energies per km^2 - century

Giant detector needed



1600 surface stations spaced 1,5 km over 3,000 km^2
and 24 fluorescence telescopes in 4 “eyes”
Baseline design completed in 2008





Fluorescence Detector

AUGER COLLABORATION

~ 400 participants - 80 institutions - 17 countries


Argentina


Australia


Bolivia


Brasil


Czech Republic


France


Germany


Italy


Mexico


Netherlands


Poland


Portugal


Slovenia

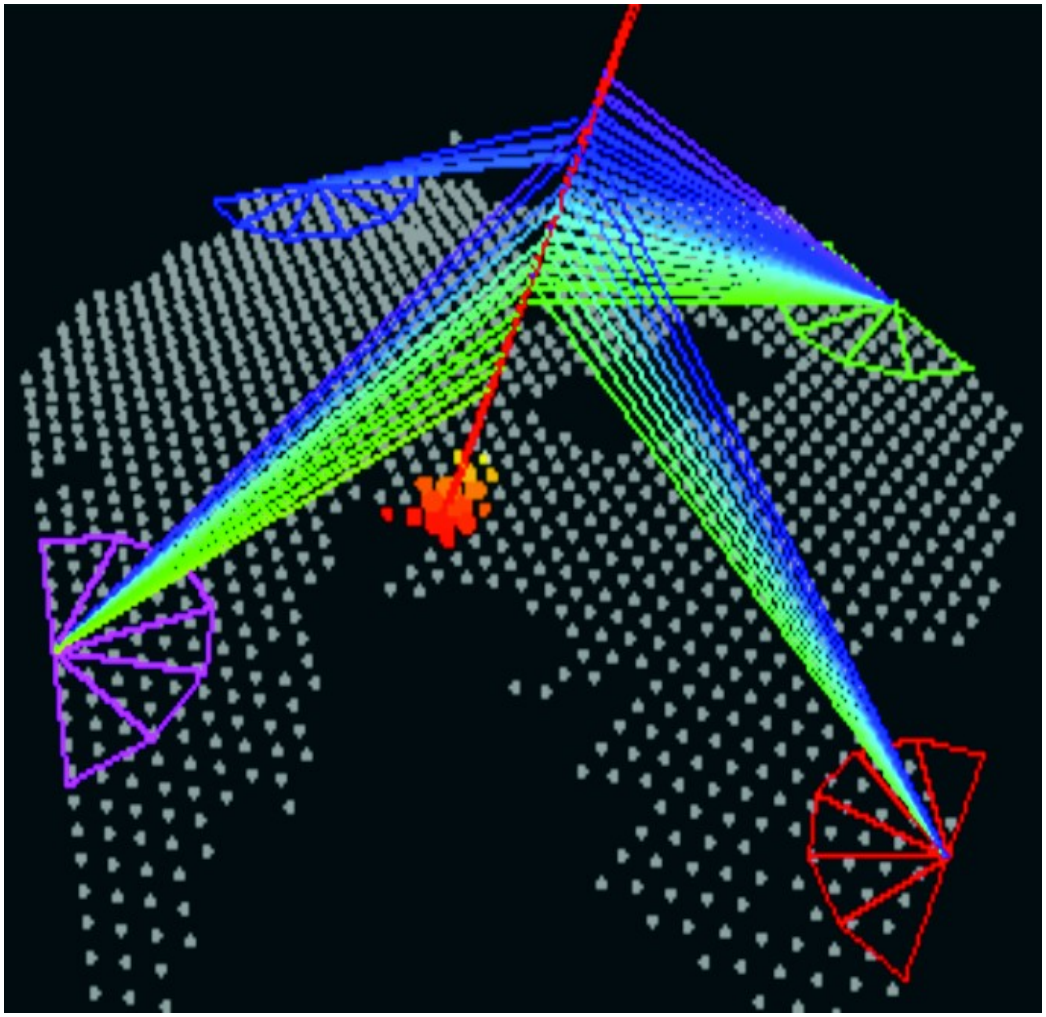

Spain


United Kingdom


USA


Vietnam

PIERRE AUGER OBSERVATORY

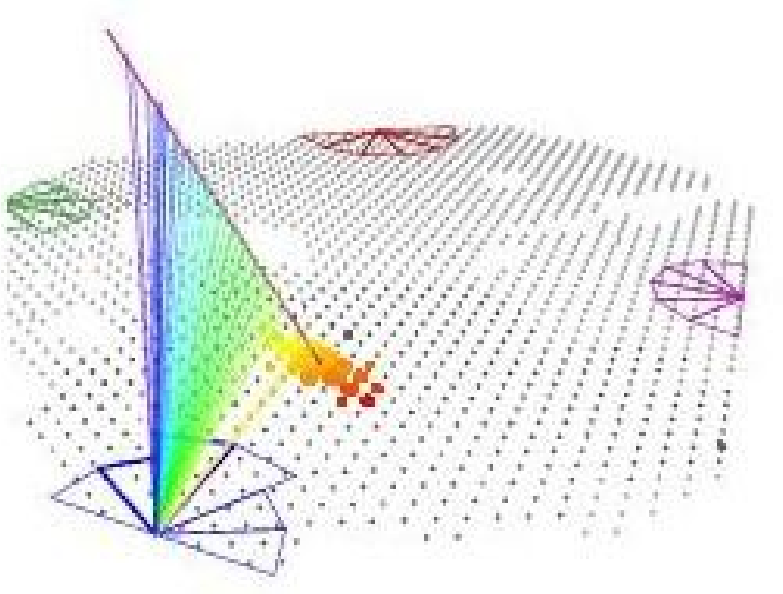


Surface stations:
"statistical power" for showers at ground level

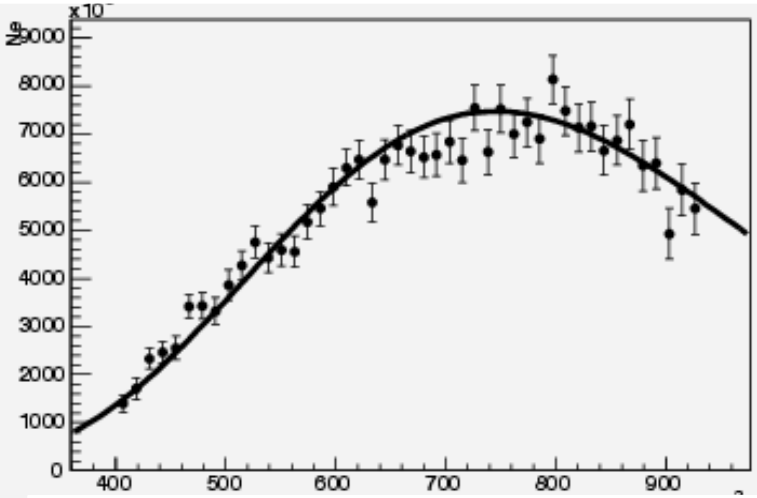
Fluorescence detectors:
Complementary view of the Shower development (13% duty cycle)

Hybrid operation:
improves precision of energy/angular calibration, consistency tests, etc.

Reconstruction of hybrid events

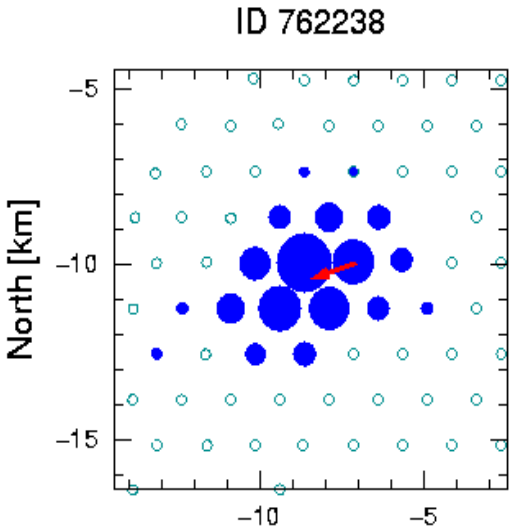


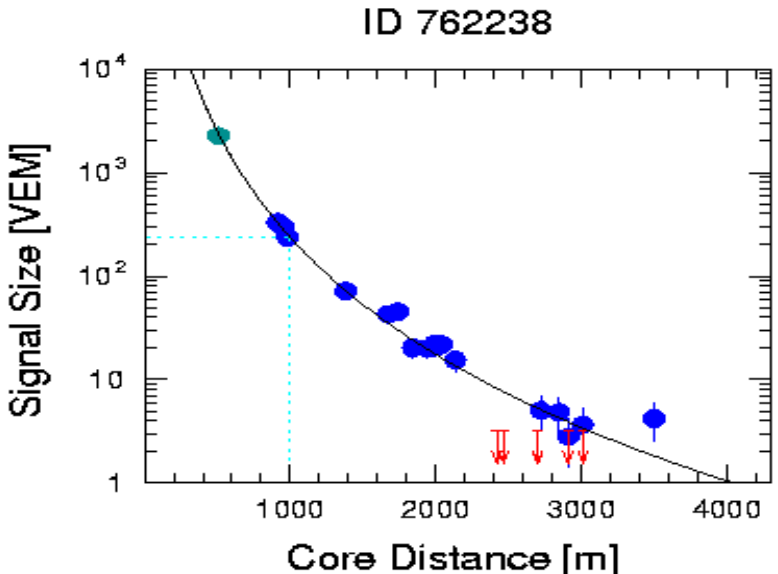
Fitted electromagnetic shower



Column density **X (gr/cm²)**

Reconstruction of surface events





Lateral density distribution

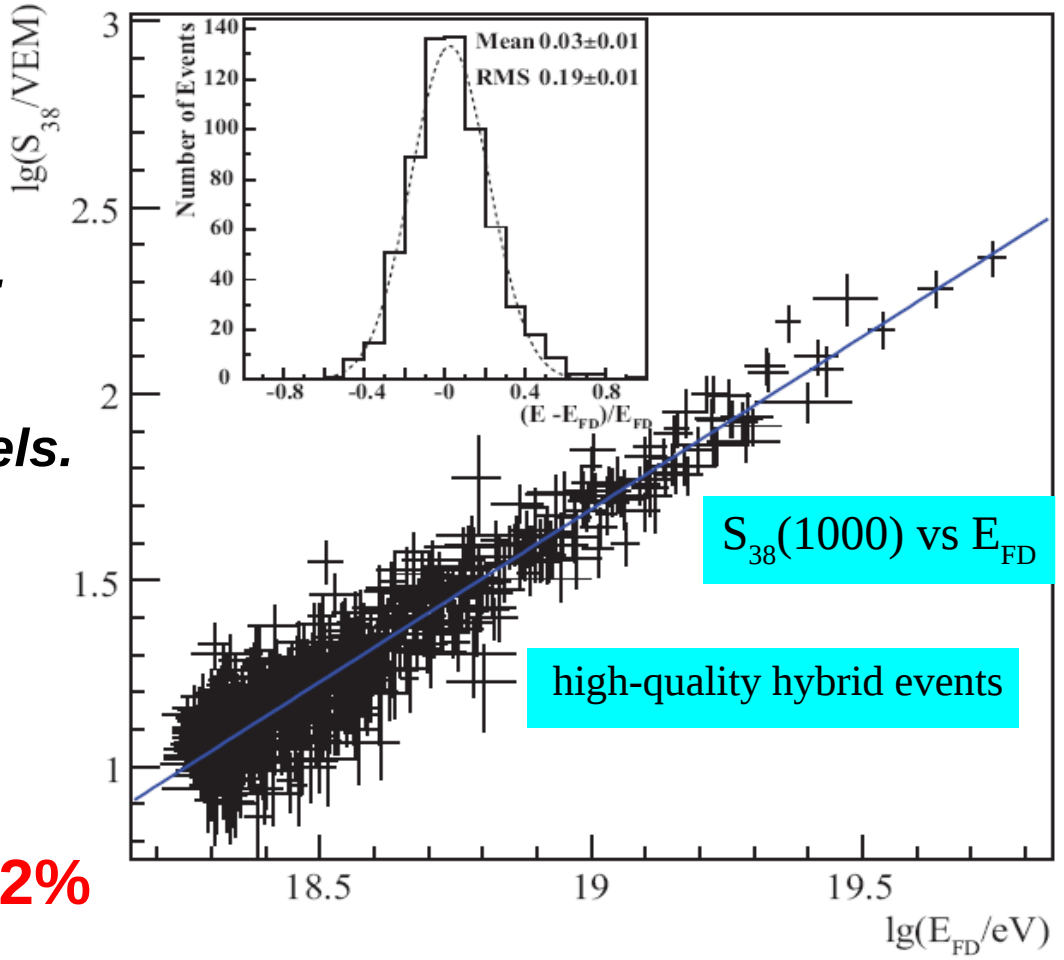
Energy Calibration

Energy scale based in fluorescence measurements. Calorimetric determination. Largely independent on composition and hadronic models.

Atmospheric attenuation accounted with constant intensity method

Resolution: 19%

Sistematic uncertainties: 22%



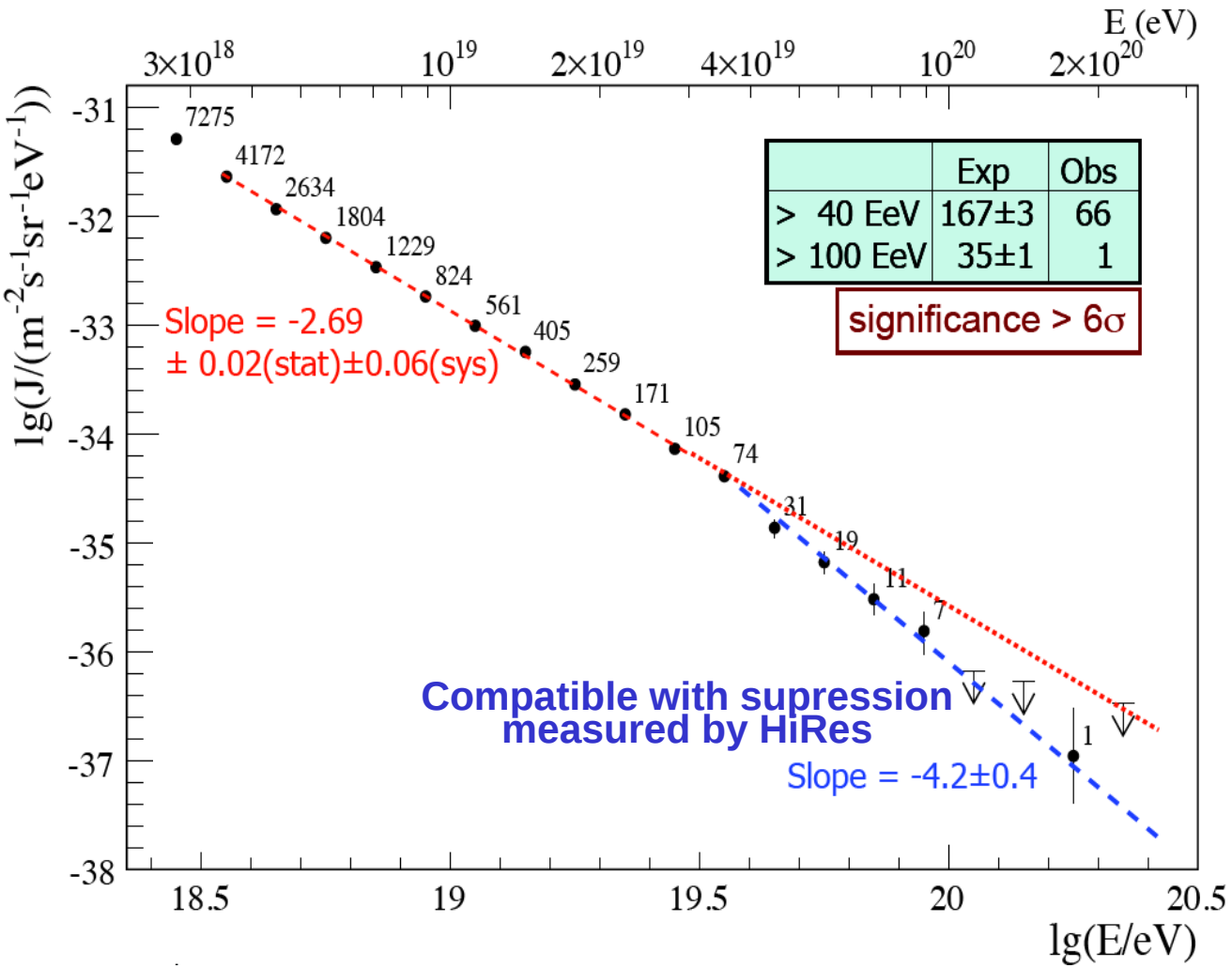
Angular resolution

Surface detectors : Limited by timing uncertainties (~12 ns)

< 1º $E > 10^{19}$ eV (> 6 stations)

RESULTS FROM THE PIERRE AUGER OBSERVATORY

SPECTRUM / COMPOSITION / ANISOTROPIES



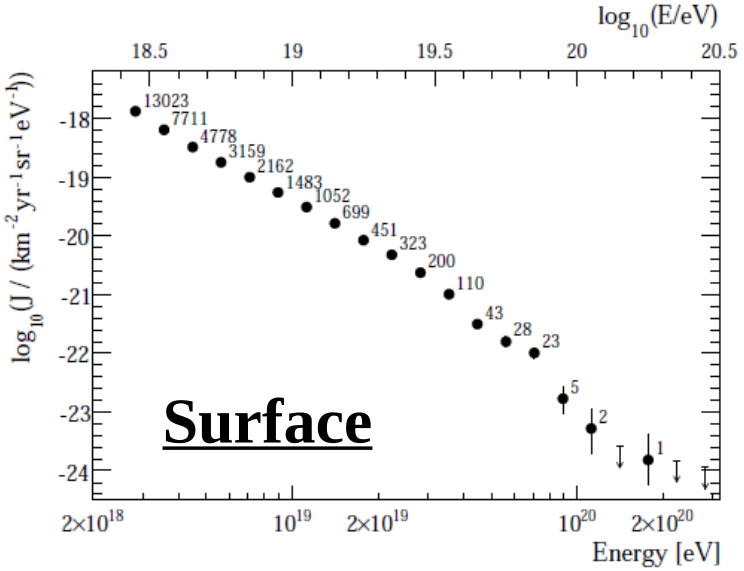
Notorious flux suppression for $E > 4 \times 10^{19}$ eV

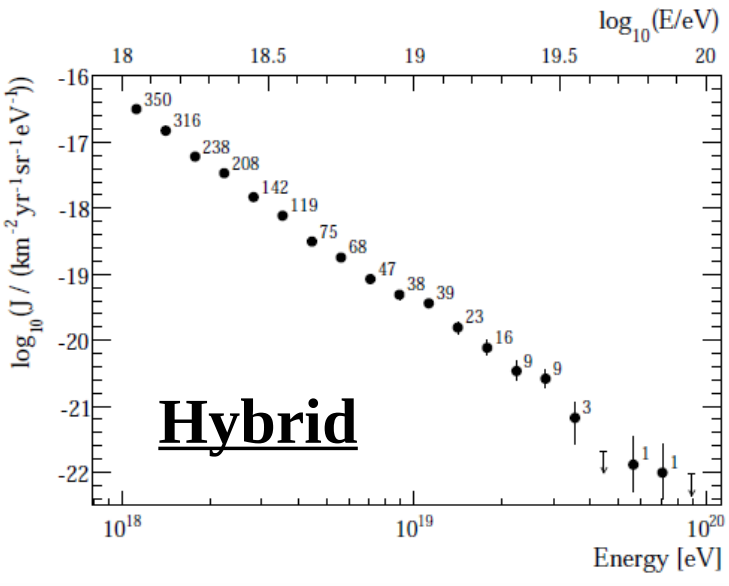
Phys. Rev. Lett. (2008)

Compatible with GZK effect

Does not reject "source exhaustion"

SPECTRUM UPDATE 2009



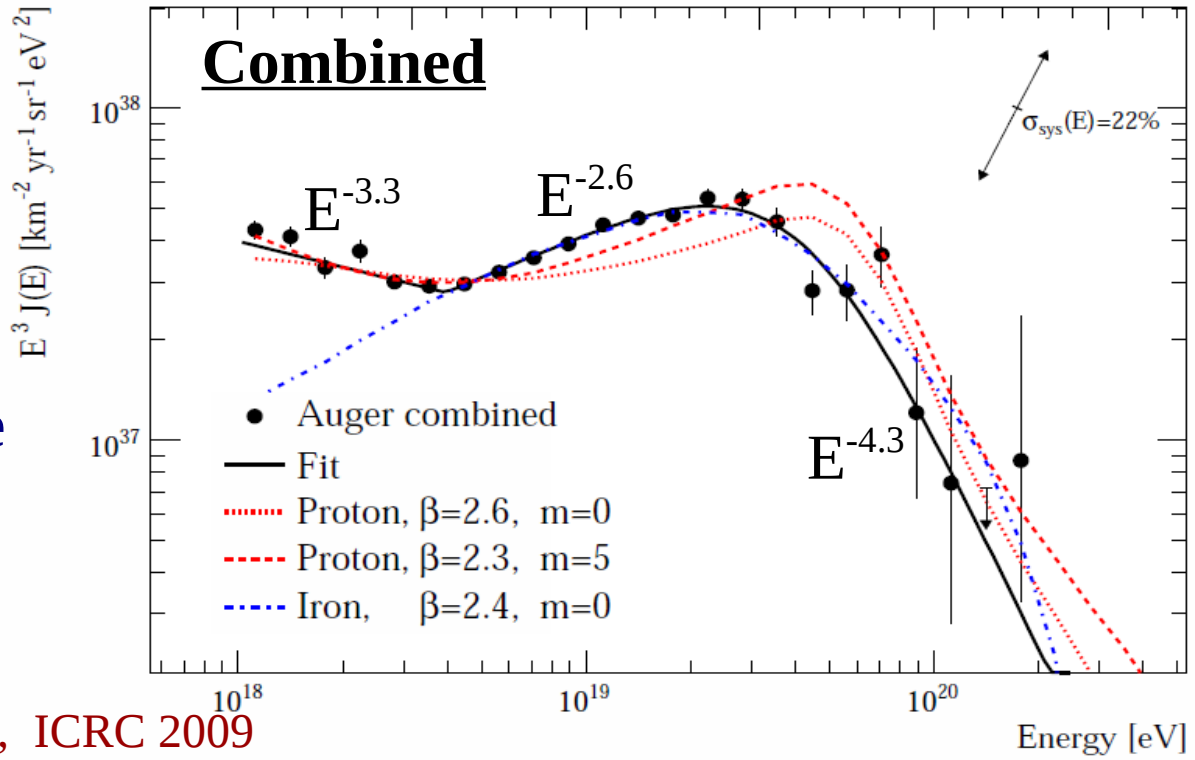


$E_{ankle} \sim 4 \times 10^{18}$ eV

$E_{1/2} \sim 4 \times 10^{19}$ eV

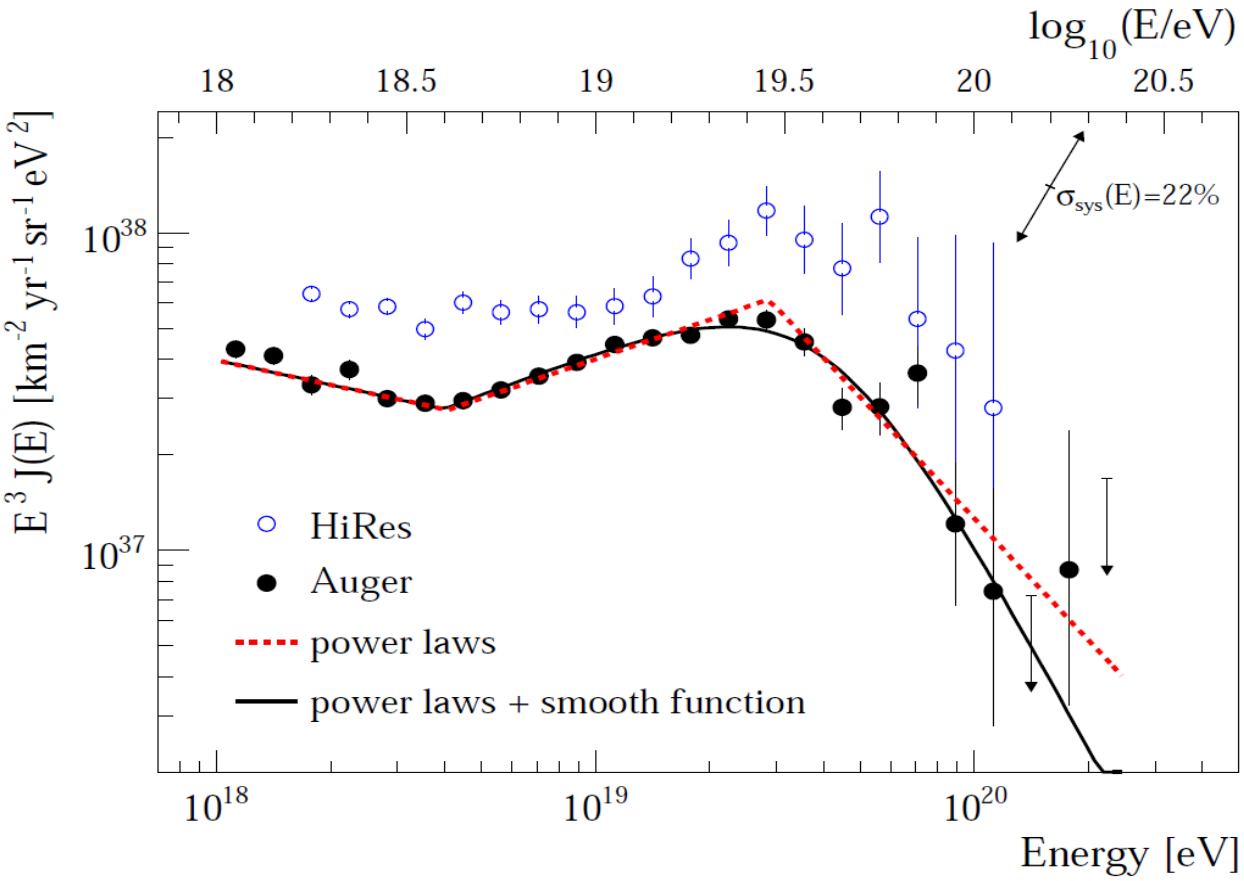
Fits to models sensitive to composition and evolution

$$J(E)=E^{-\beta}(1+z)^{m}$$



F. Schussler for the Auger Collab., ICRC 2009

Comparison with HiRes

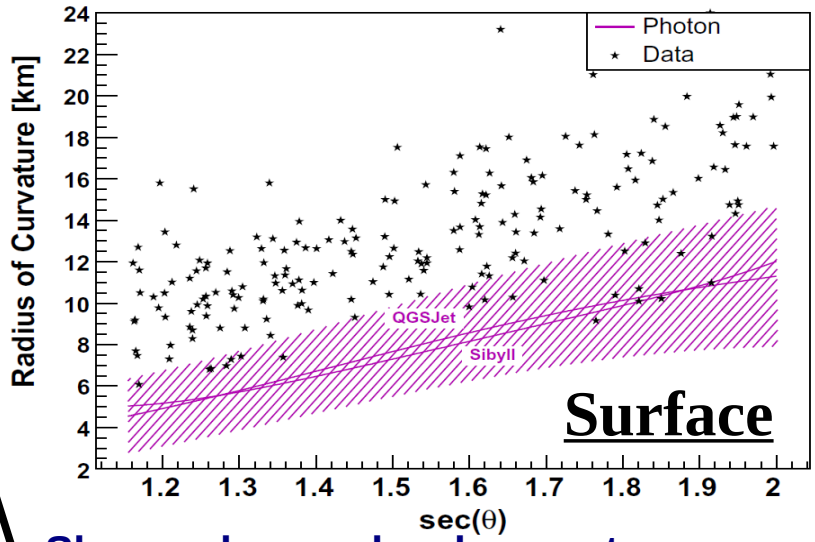


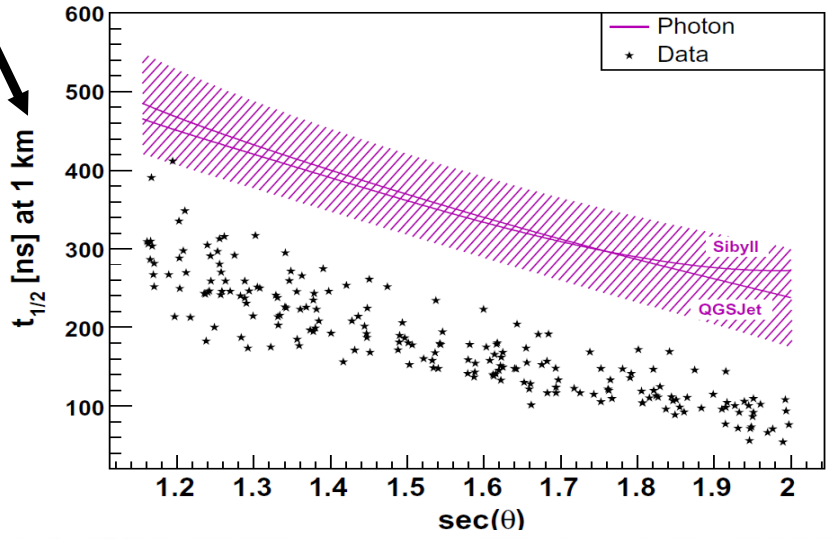
Consistent within energy scale uncertainties

COMPOSITION: BOUNDS ON PHOTONS

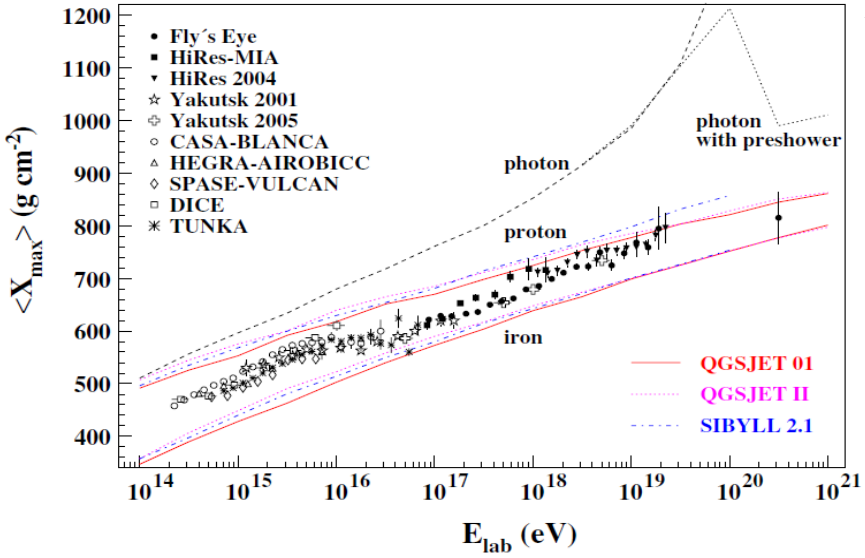
Photon showers predominantly electromagnetic
Longer "risetimes"

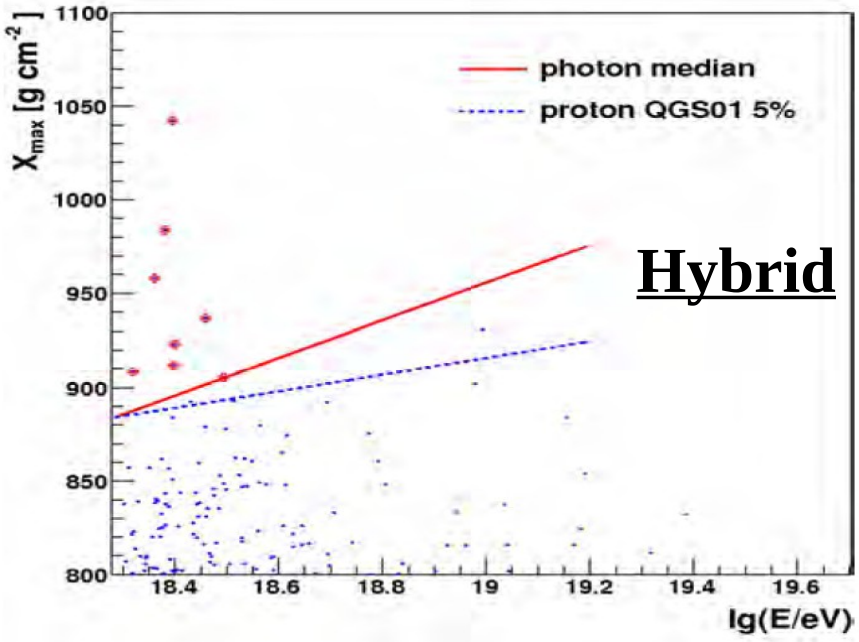
Astroparticle Physics
(2007, 2008)





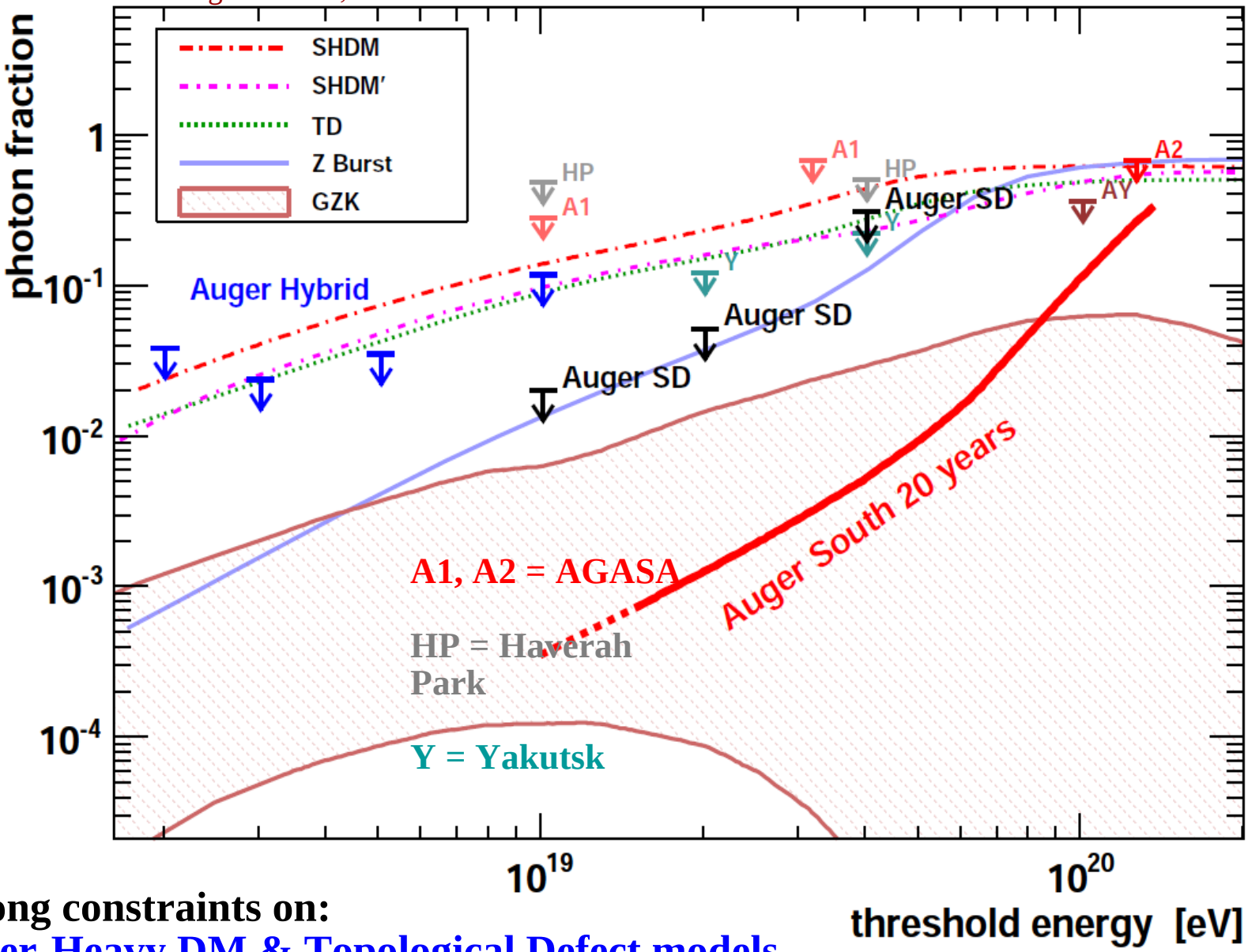
Slower shower development:
Smaller curvature radius and larger X_{max}





2009 update on photon fractions

P. Homola for the Auger Collab., ICRC 2009



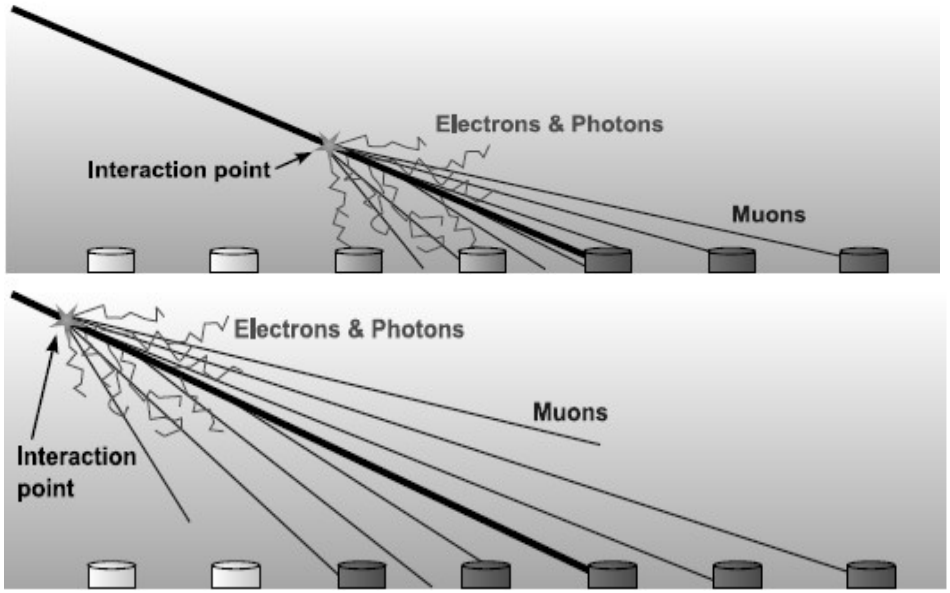
Strong constraints on:

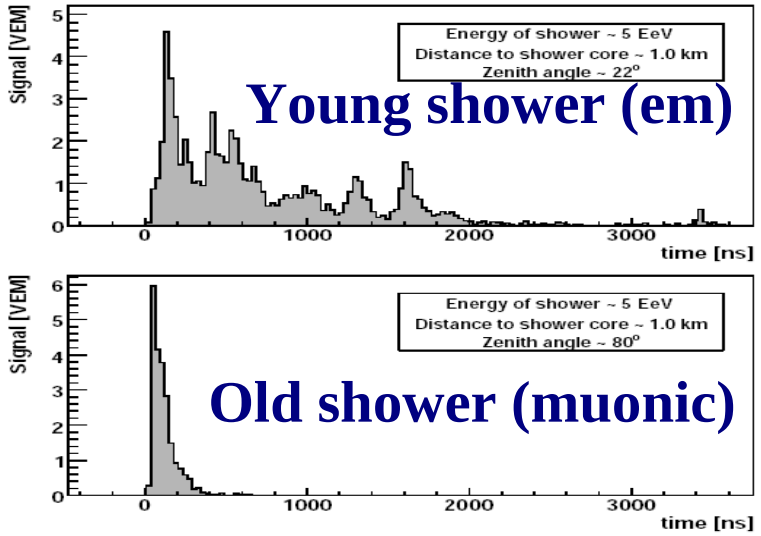
Super-Heavy DM & Topological Defect models

COMPOSITION: BOUNDS ON NEUTRINOS

Neutrinos, unlike hadrons, can induce showers close to the ground (downgoing υ's and earth-skimming υ_τ)

Phys. Rev. Lett. (2008)





FOOTPRINTS:

Young horizontal showers by earth-skimming υ_τ

- 60% of signal in detectors with large area/peak ratio
- Elongated shape: L/W > 5
- Propagation at v ~ c

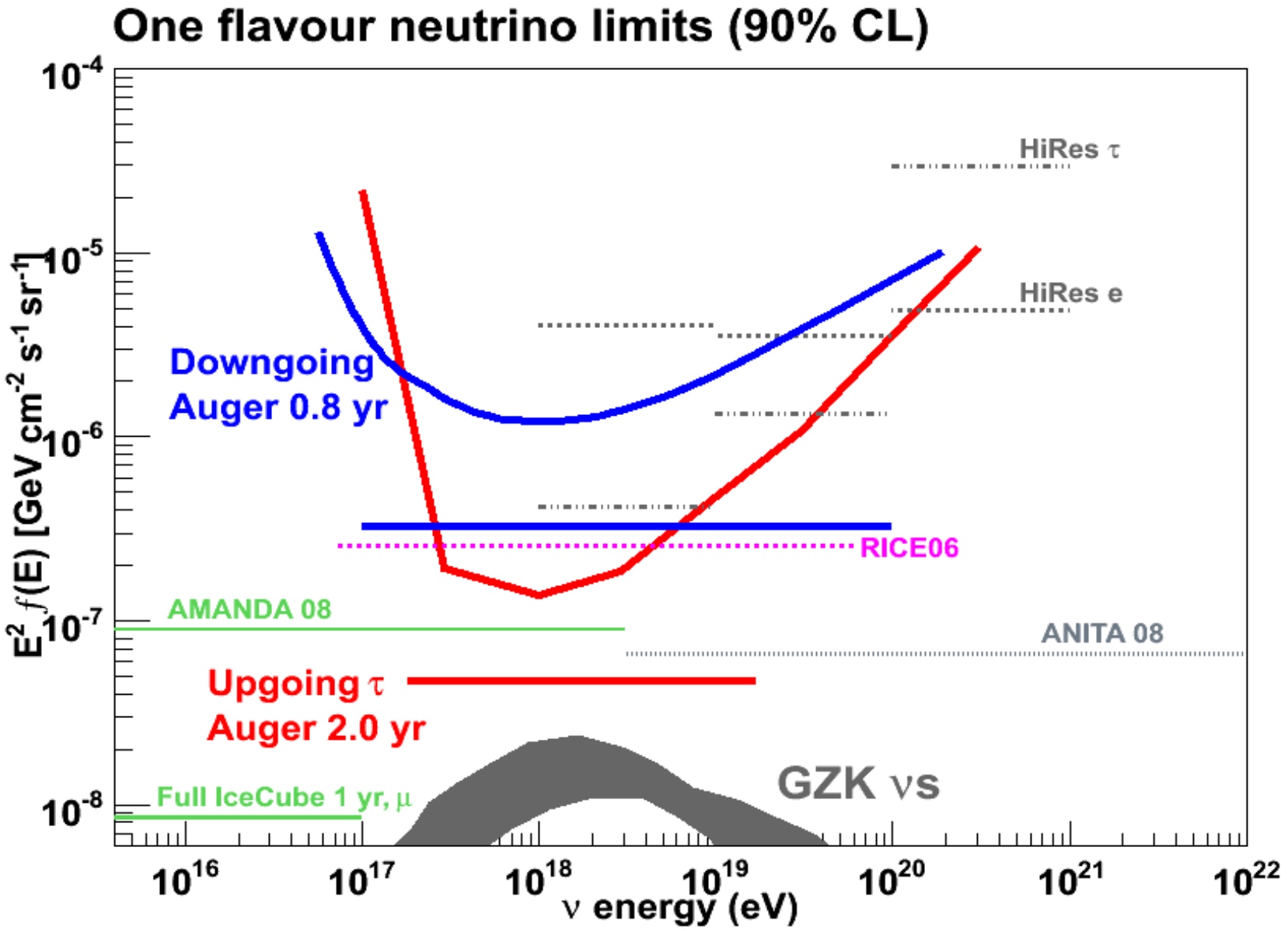
Inclined young showers by downgoing υ

- Fisher method with "training" early data
- L/W > 3
- Compatible average speed

CANDIDATES: 0

2009 update on neutrino bounds

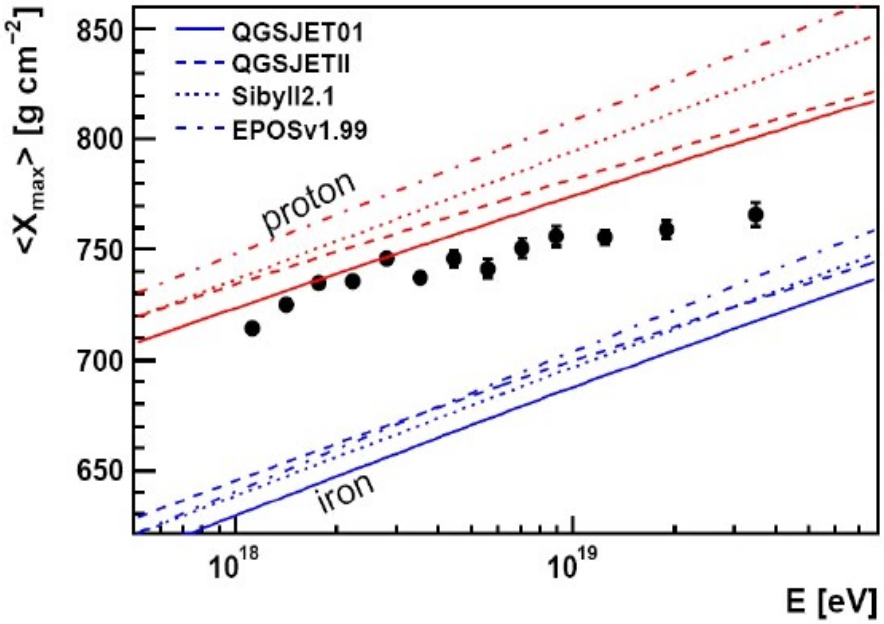
J. Tiffenberg for the Auger Collab., ICRC 2009

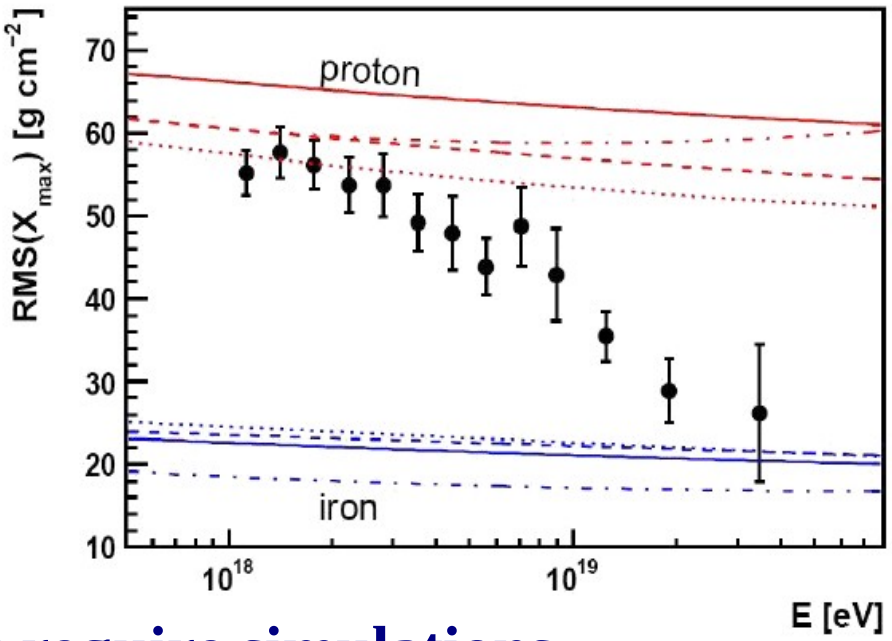


COMPOSITION: LIGHT OR HEAVY?

Elongation rate flattens at high energy J. Bellido for the Auger Collab.,ICRC 2009

Fluctuations decrease with energy





Composition estimates require simulations

Current hadronic models suggest increasing average mass

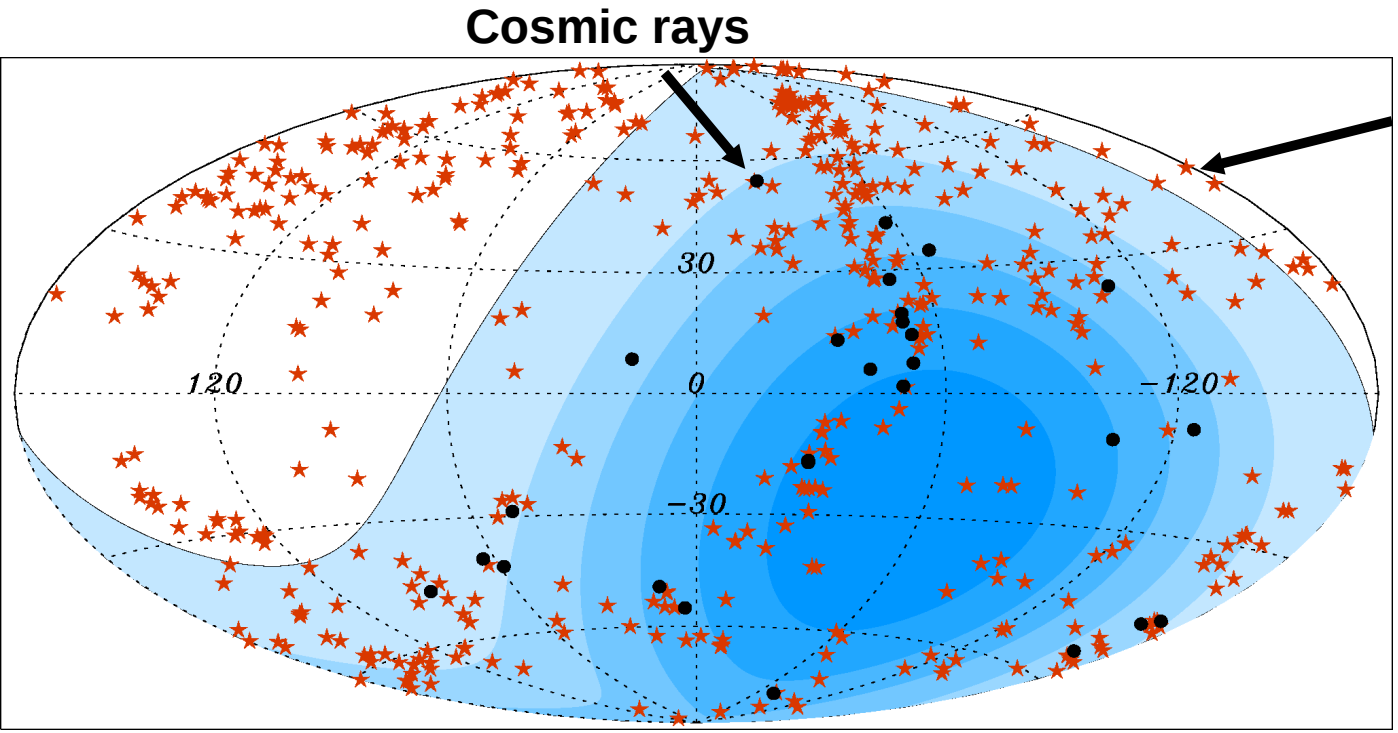
(with large uncertainties)

HiRes: compatible with proton-dominance

Composition relevant for: acceleration processes, deflections, spectrum, cosmogenic neutrinos, ...

ANISOTROPIES: CORRELATION WITH NEARBY AGN

Science (2007) Astroparticle Physics (2008)



AGN at D < 75 Mpc from Véron-Cetty catalogue

$E_{min} \sim 6 \times 10^{19}$ eV

Evidence for nearby extragalactic origin and GZK effect

Suggests proton composition

(conflict with X_{max} measurements? Or with extrapolation of hadronic interactions? Or very weak magnetic fields?)

DOES NOT IDENTIFY AGN AS SOURCES

Catalogue is incomplete, inhomogeneous, no selection function

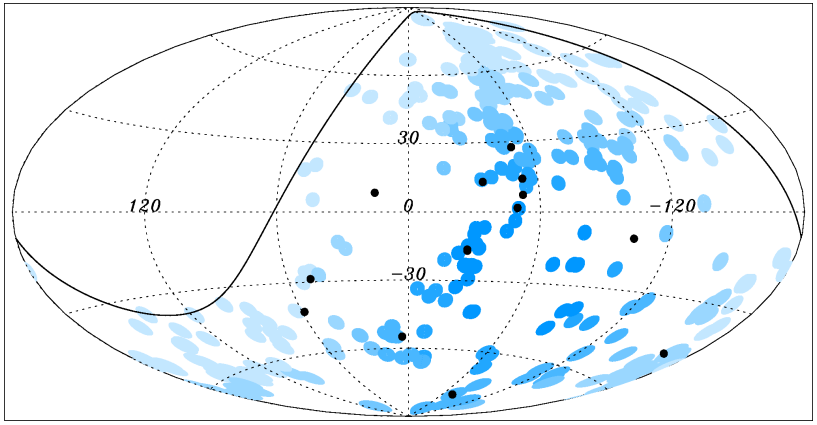
Evidence for anisotropy

Parameters fixed by exploratory scan (maximum departure from isotropy)

Jan 2004 – May 2005

4390 km² sr yr

9/14 correlations



E > 5.5x10¹⁹ eV

D < 75 Mpc

consistent with GZK HORIZON

ψ < 3.1°

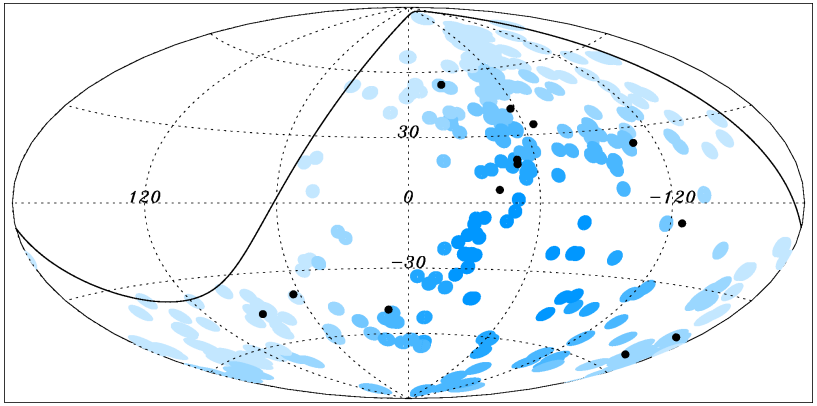
(21% exposure-weighted area)

Evidence in independent data

May 2005 - Aug 2007

4500 km² sr yr

9/13 correlations



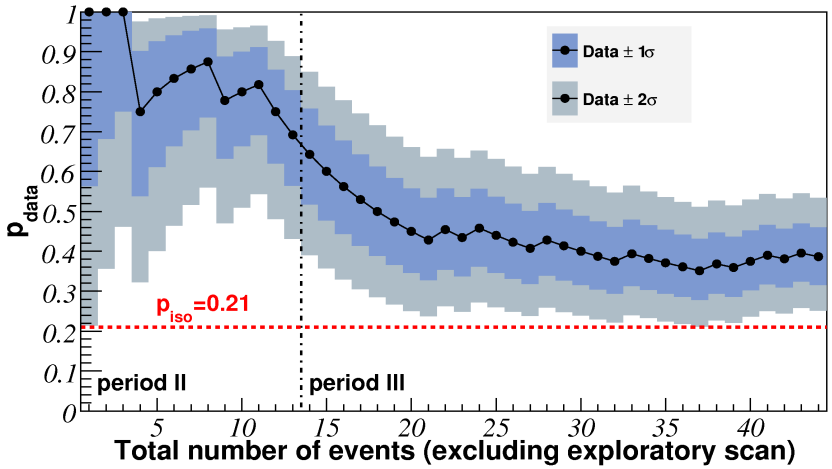
Isotropic probability P < 1%

Update 2009

May 05 - March 09

12650 km² sr yr

17/44 correlations



Anisotropy signal has not strengthened

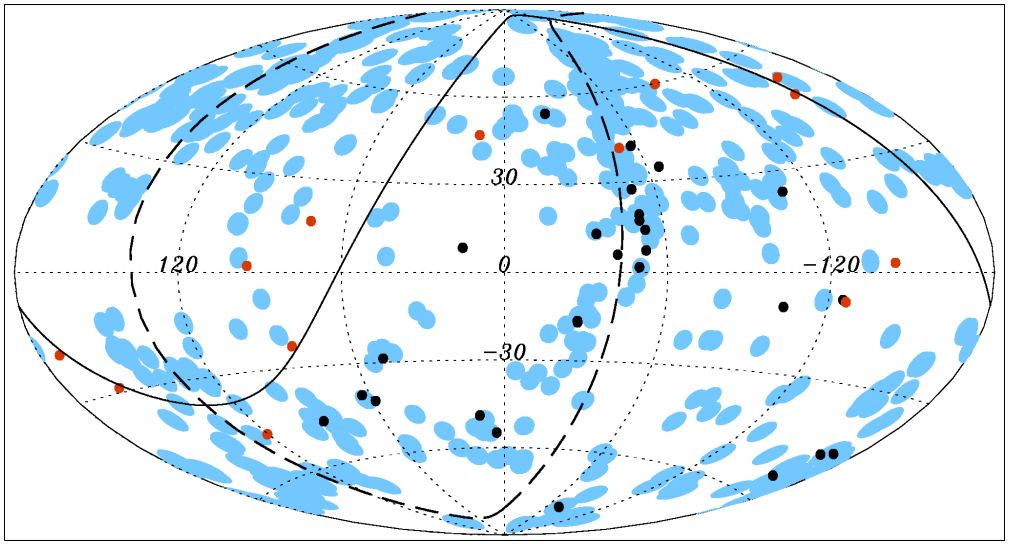
Correlation ~ 40%

P = 0.6%

J. Hague for the Auger Collab., ICRC 2009

Search by HiRes

13 stereo events with highest energy



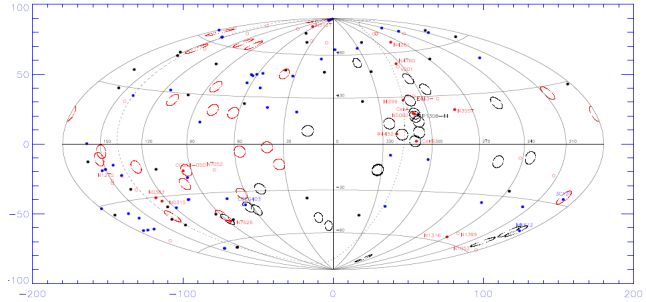
2 / 13 correlations at 3.1º

with AGN at D < 75 Mpc

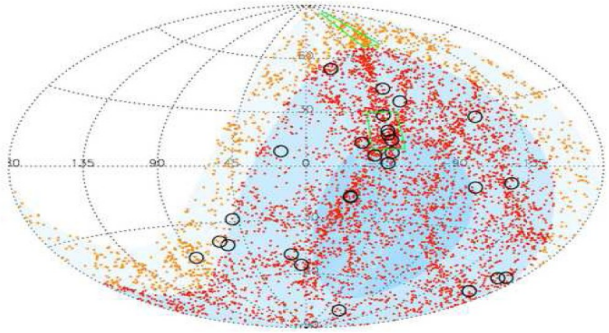
Search by Telescope Array

2 / 3 correlations (ICRC 2009)

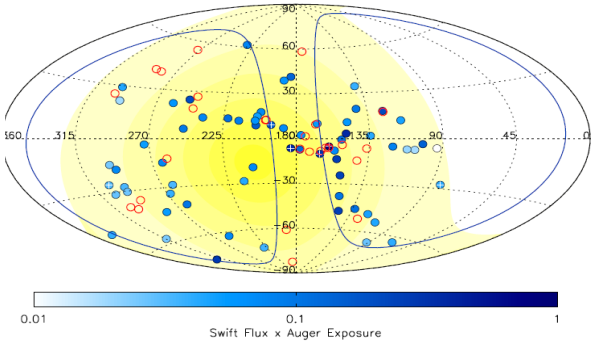
SOME INDEPENDENT INTERPRETATIONS (DATA AUG 2007)



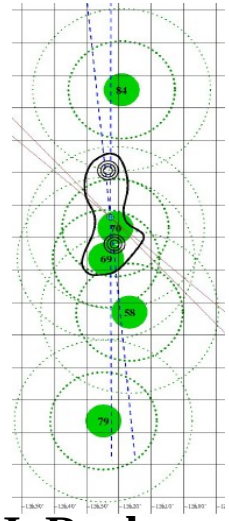
N. Nagar and J. Matulich
Nearby radiogalaxies with jets



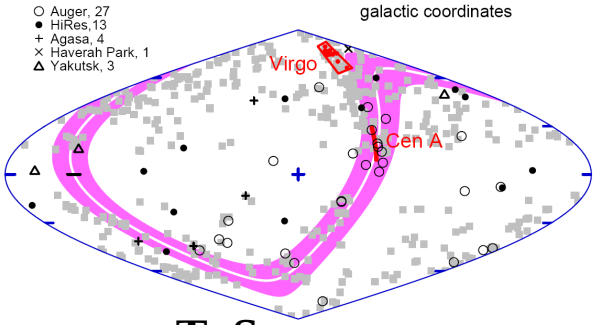
G. Ghisellini et al.
Spiral Galaxies in HIPASS



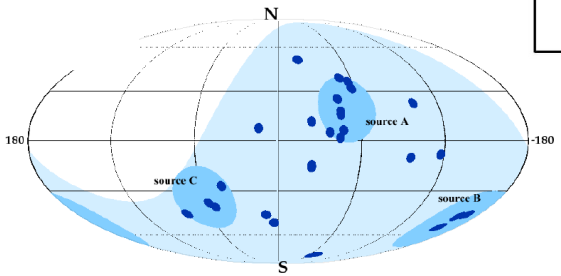
M. George et al.
AGN in Swift-BAT (X-rays)



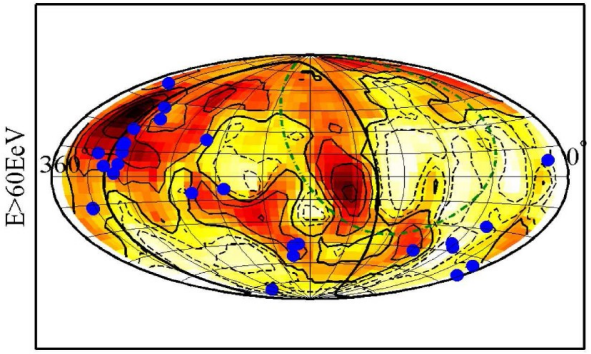
J. Rachen
Cen A radiolobes



T. Stanev
Supergalactic plane



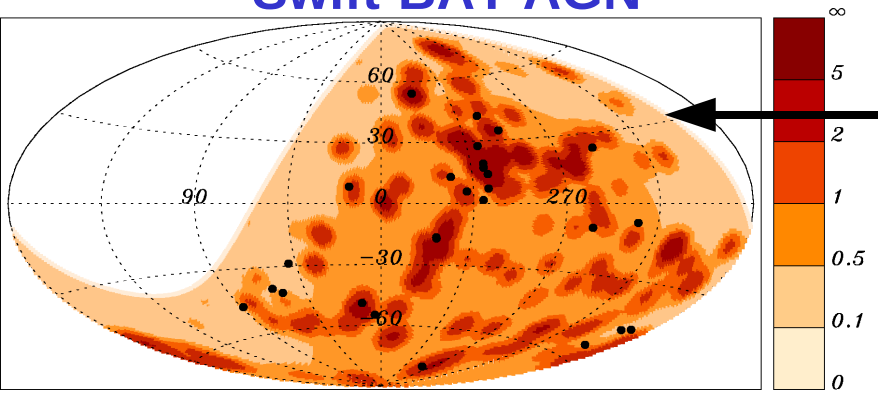
Wibig and Wolfendale
3 sources, 20º deflections

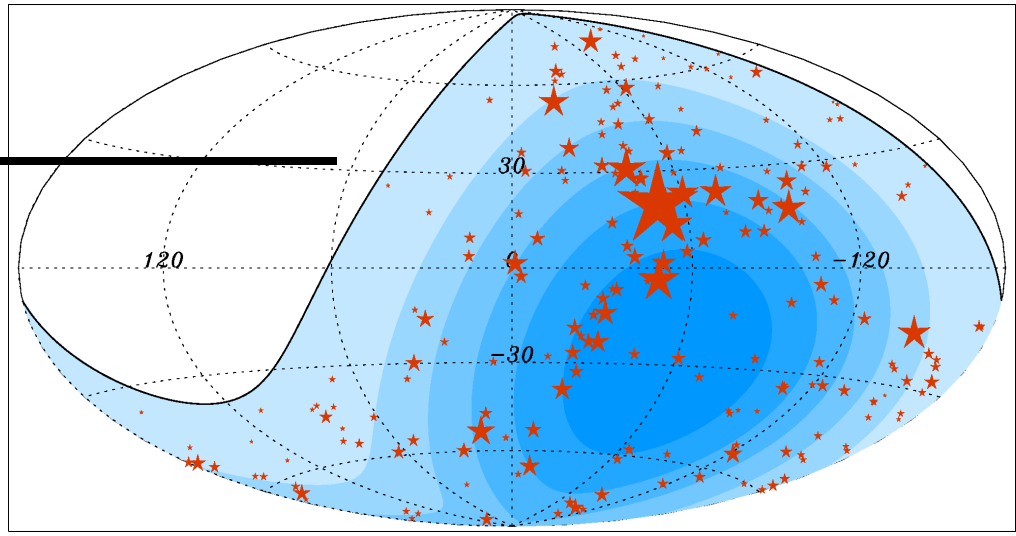


Kashti and Waxman
IRAS – PSCz galaxies

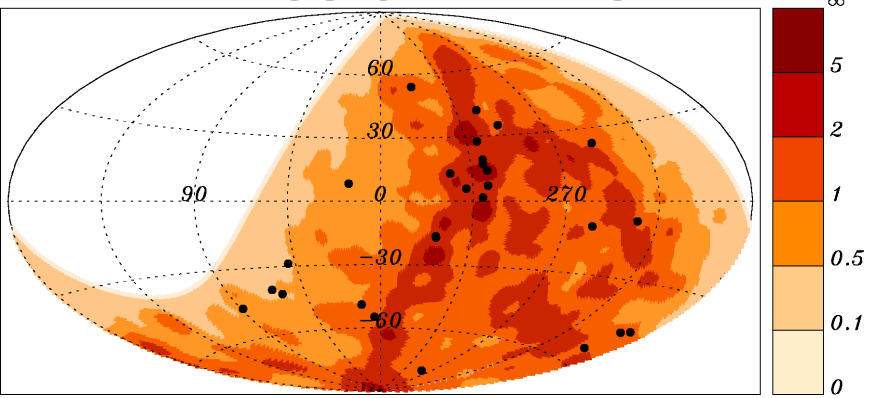
SOME EXAMPLES OF ALTERNATIVE SCENARIOS

Swift-BAT AGN

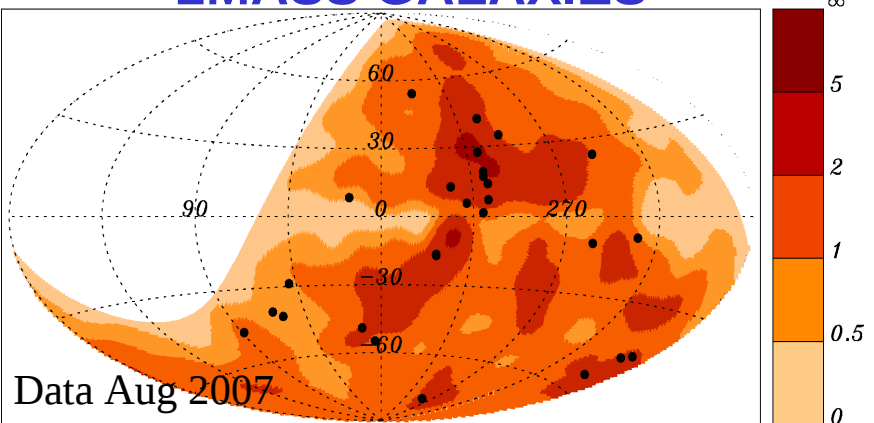




HIPASS GALAXIES



2MASS GALAXIES



Data Aug 2007

Based on statistically complete flux-limited catalogues

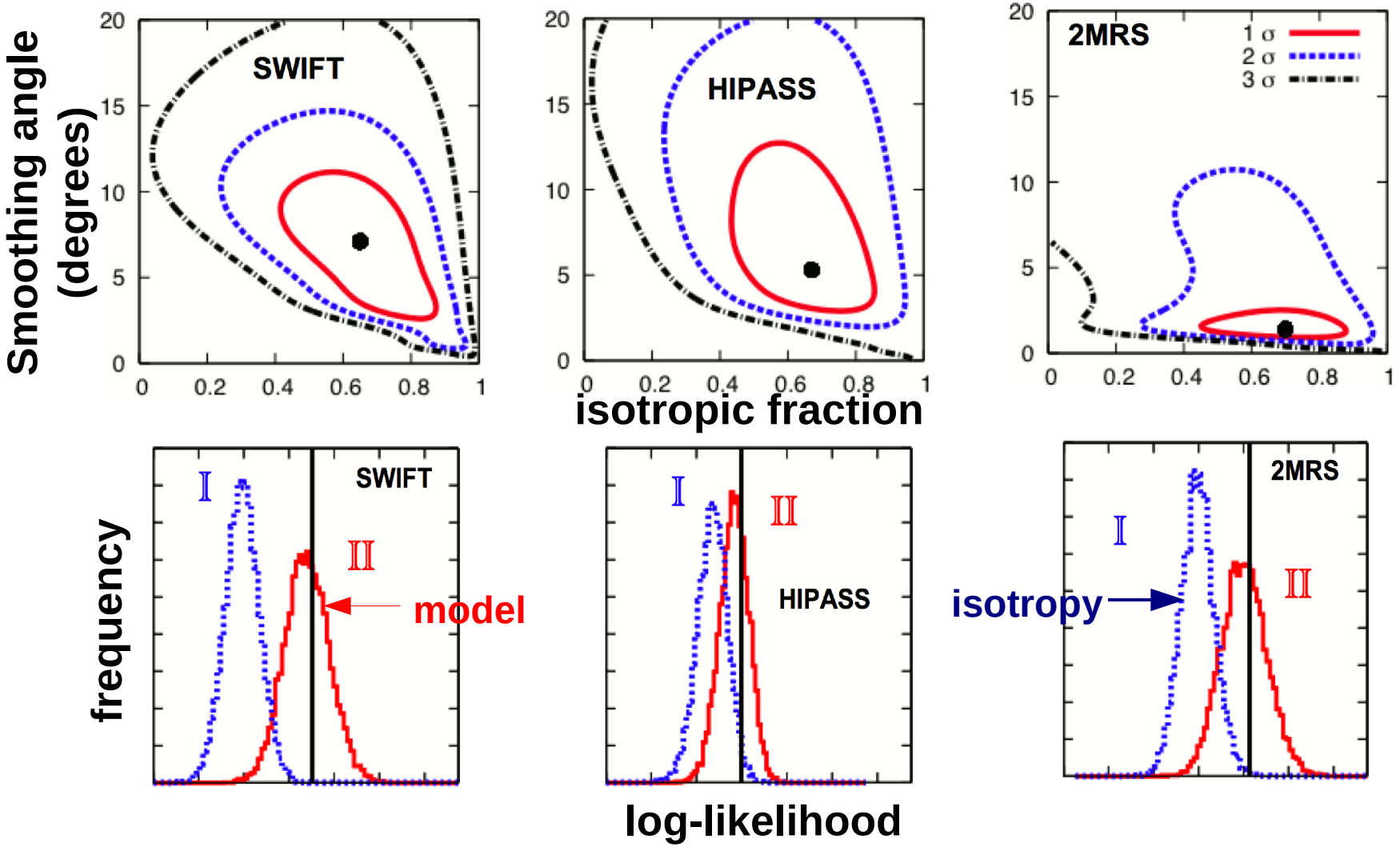
Smoothed density maps weighted by relative exposure, GZK attenuation, and flux

Likelihood tests compatible with correlation with alternative populations of nearby extragalactic objects

LIKELIHOOD TESTS WITH DATA UNTIL MARCH 2009

58 cosmic rays with E > 5.5 x 10 ^{19} eV

J. Aublin for the Auger Collab.,ICRC 2009



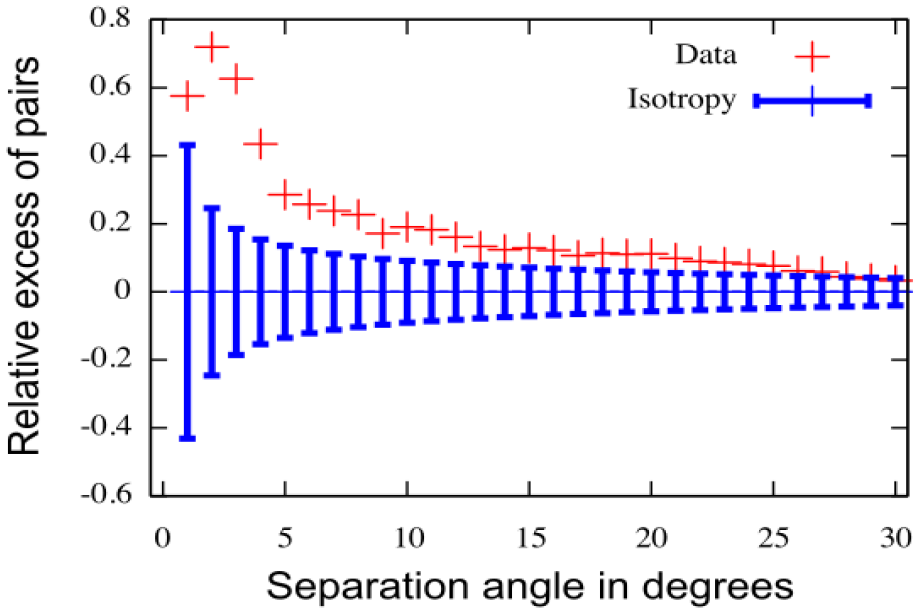
Departures from isotropic expectations in all cases

Consistency with all models considered for appropriate parameters

MORE DATA IS NEEDED TO DISCRIMINATE

OTHER TEST: CROSS-CORRELATION

Cosmic rays: 58 events with E > 5.5 x 10^{19} eV



Objects: Volume-limited (200 Mpc) sample

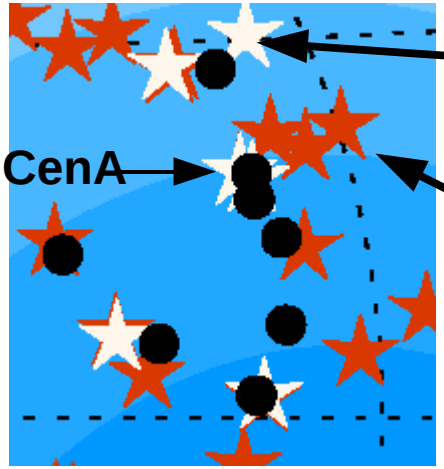
from 2MASS galaxies

(similar results for Swift-BAT AGN and HIPASS galaxies)

J. Aublin for the Auger Collab.,ICRC 2009

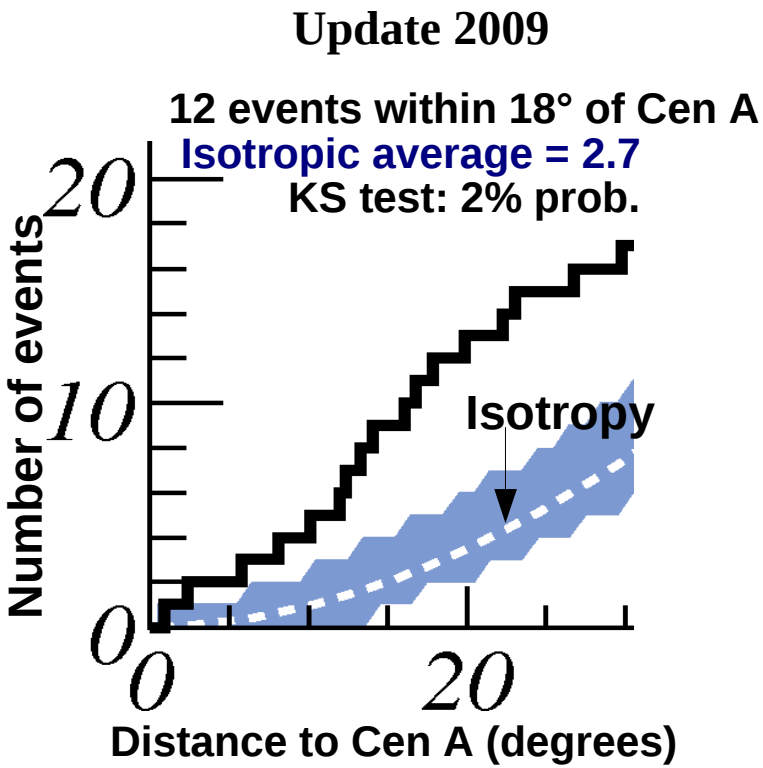
INTERESTING REGION

Excess in region around Cen A



Data Aug 2007

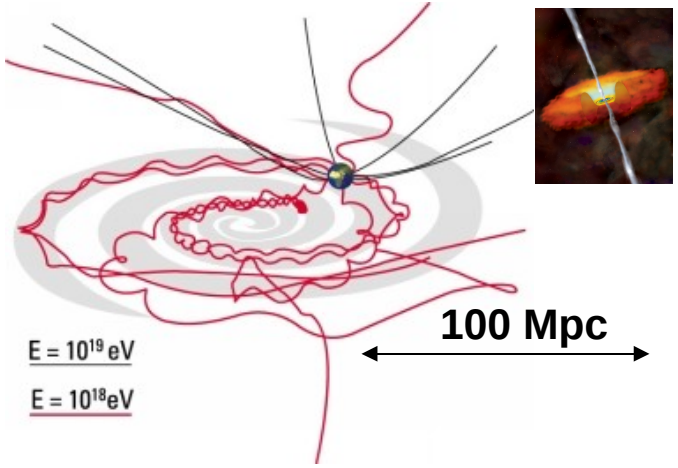
Many objects in same region
(AGN, radiogalaxies,
"ordinary" galaxies)



J. Hague for the Auger Collab., ICRC 2009

No events (E > 5.5 x10^{19} eV) within 20° of M87

exposure is 3 times smaller



CONCLUSION

PERSPECTIVES AND CHALLENGES FOR COSMIC RAY ASTRONOMY

FLUX SUPPRESSION
CORRELATION WITH NEARBY MATTER
Compatible with origin in extragalactic sources within "GZK horizon"
ANGULAR SCALE OF FEW DEGREES
Light composition? Hadronic models / cross sections? Weak magnetic fields?
INTERESTING EXCESS IN REGION AROUND Cen A
No preferential candidate source population identified

CHALLENGES

Identify the most relevant source population within the GZK horizon

Identify individual sources

Characterize galactic and intergalactic magnetic fields

Auger South

Baseline design was inaugurated in November 2008.

Enhancements under construction:

AMIGA: underground muon counters (composition studies) and denser sub-array to extend full efficiency to lower energies.

HEAT: extends fluorescence measurements to lower energies.

Potential extension under study.

Auger North

20.000 km^2 planned. Site: Lamar, Colorado, EEUU.

Other projects: **Telescope Array, JEM-EUSO, etc.**

EXPOSURE TO COSMIC RAYS
Past, present and future experiments