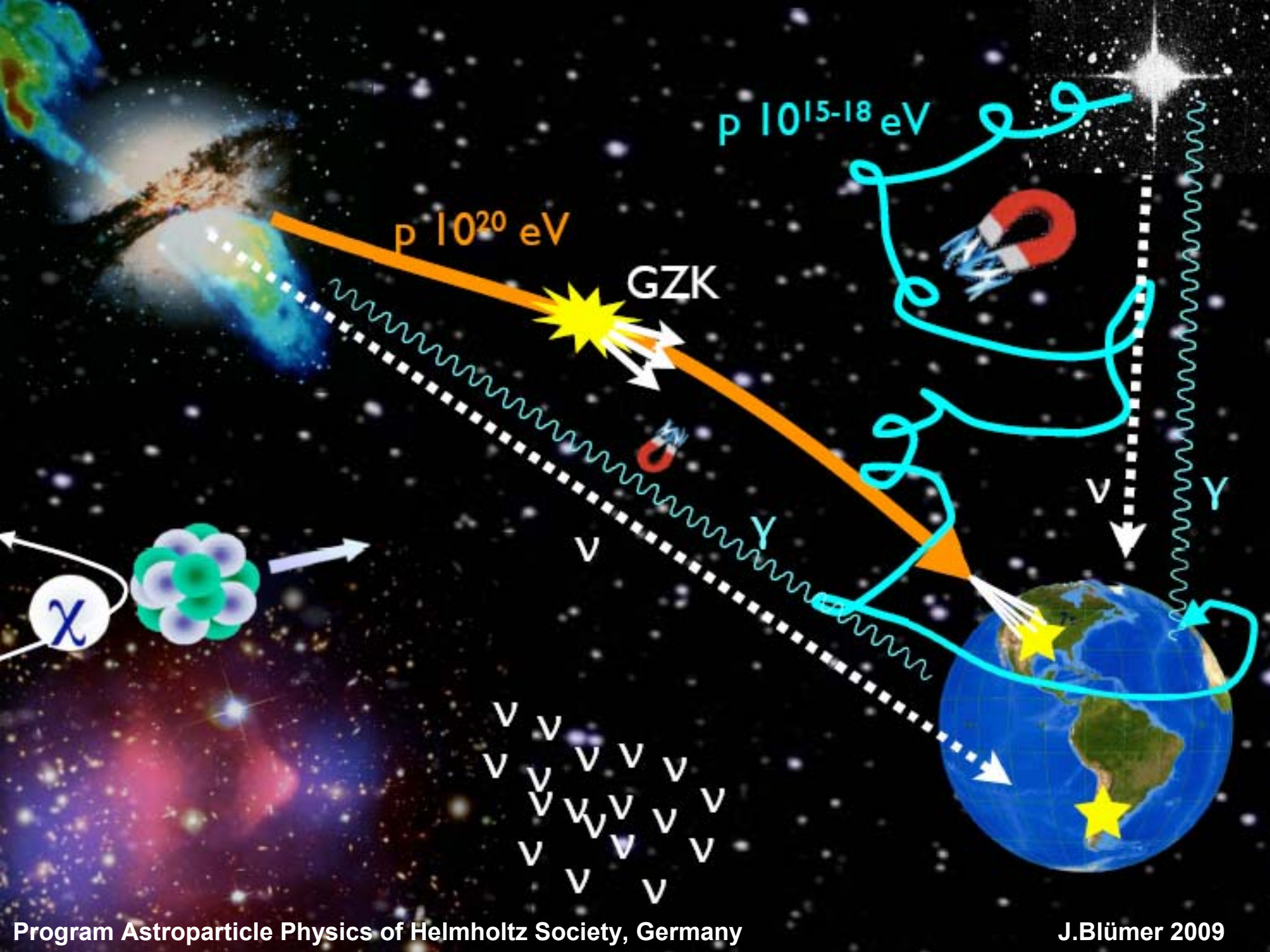
The Pierre Auger Observatory
Status - First Results - Plans

Andreas Haungs for the Pierre Auger Collaboration
Forschungszentrum Karlsruhe
Germany
haungs@ik.fzk.de



Program Astroparticle Physics of Helmholtz Society, Germany

J.Blümer 2009

Pierre Auger Observatory: Science Objectives

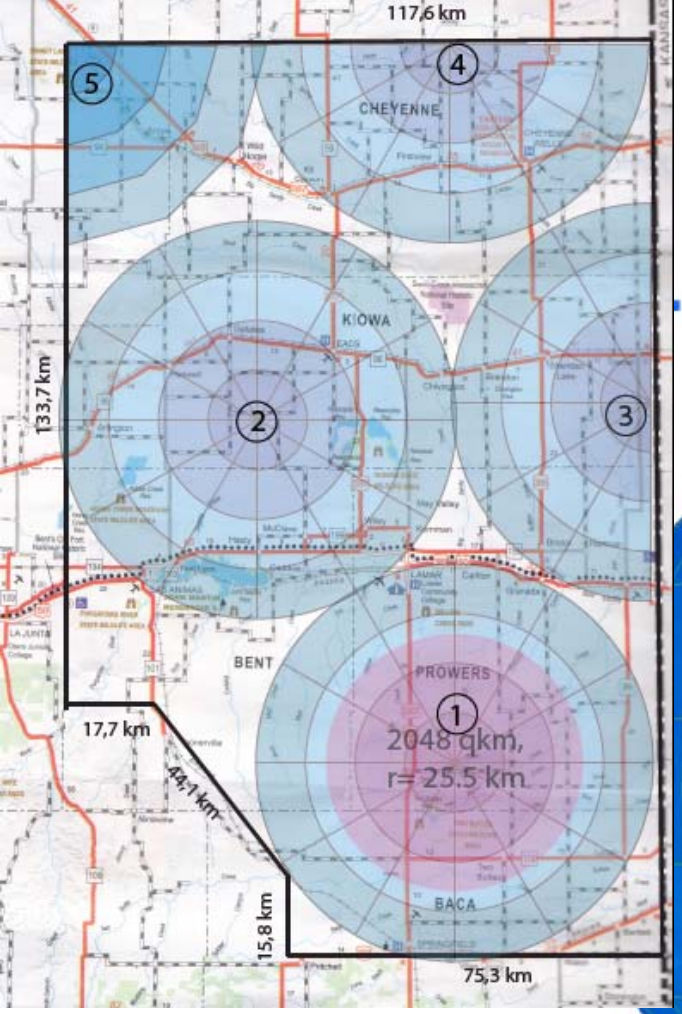
- **understand the nature, origin and propagation of UHECR**
  - **point sources?**
  - **An-/Isotropy of arrival directions?**
  - **GZK cut-off or continuing spectrum or other structures?**
  - **primary particle mass, type?**
  - **acceleration or decay of exotics?**
- **measure cosmic rays with high statistics and quality**
  - **aperture > 7 000 km^2sr @$10^{19}eV$ in each hemisphere**
  - **~ degree angular resolution, zenith angle θ°... 90°**
  - **primary particle discrimination (light, heavy, γ, ν)**
  - **calorimetric energy calibration**

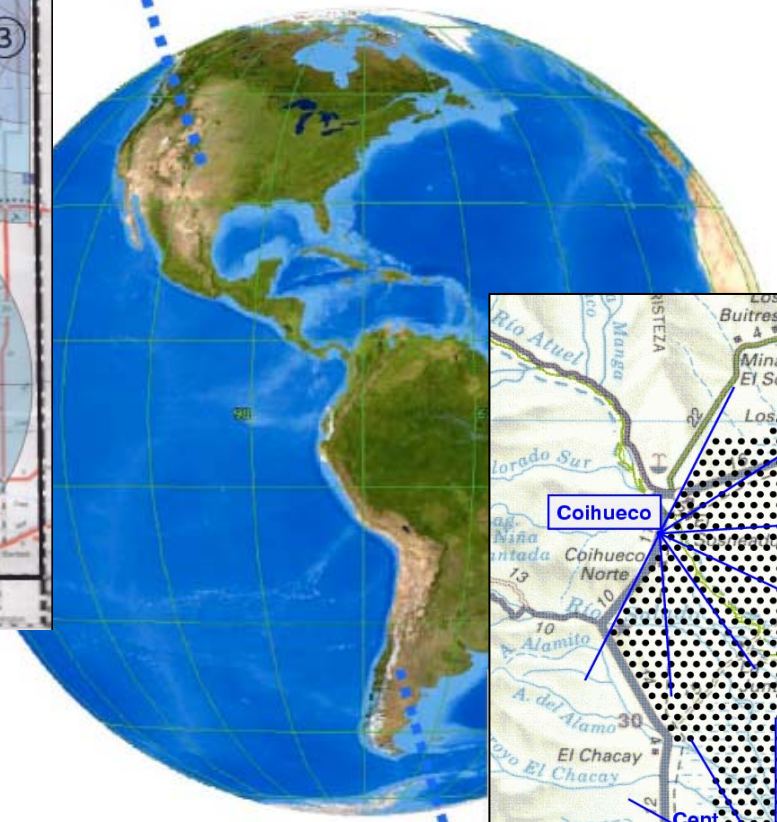
➔ **hybrid design: surface detectors and fluorescence telescopes**

  - **measurement of direction, energy and composition of primaries**

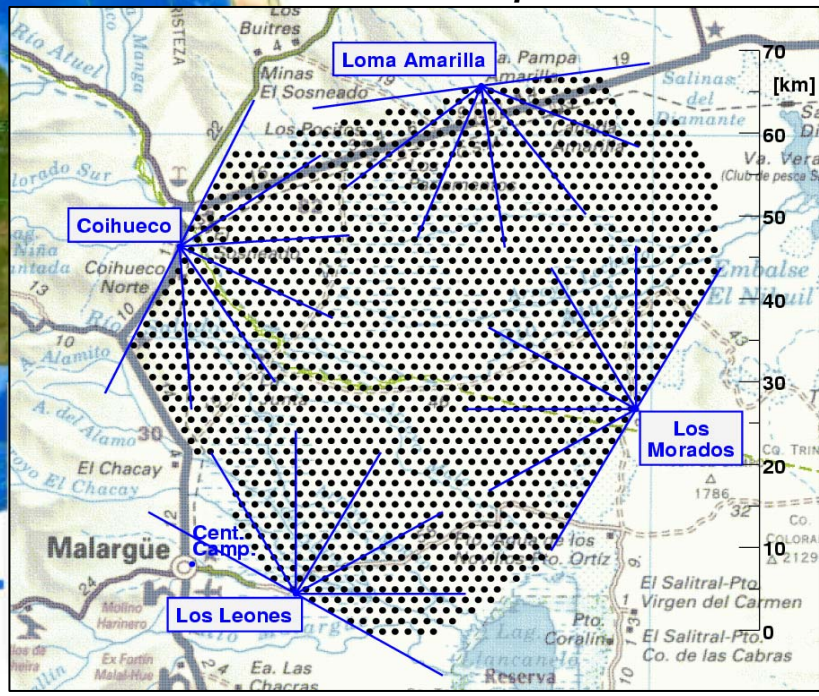
The Pierre Auger Project

High statistics
Hybrid detection
Full sky coverage





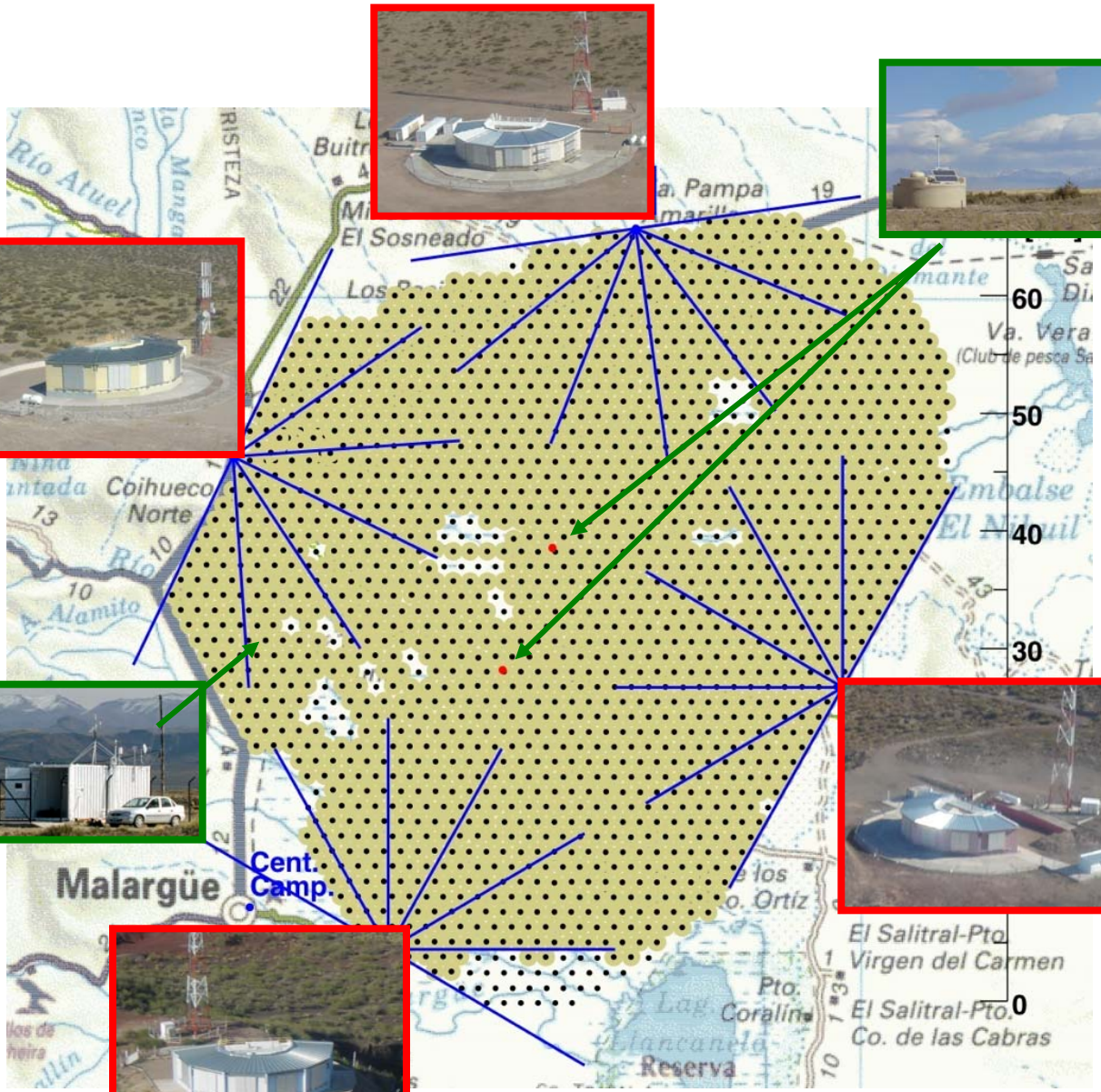
1992 Paris workshop
1996 Design report
1999 Ground breaking
2001 Engineering array
2003 Construction phase
2008 Completion



Northern Observatory
4000 detectors 20,000 km²

Southern Observatory
1600 detectors 3,000 km²

Southern Pierre Auger Observatory completed July 2008



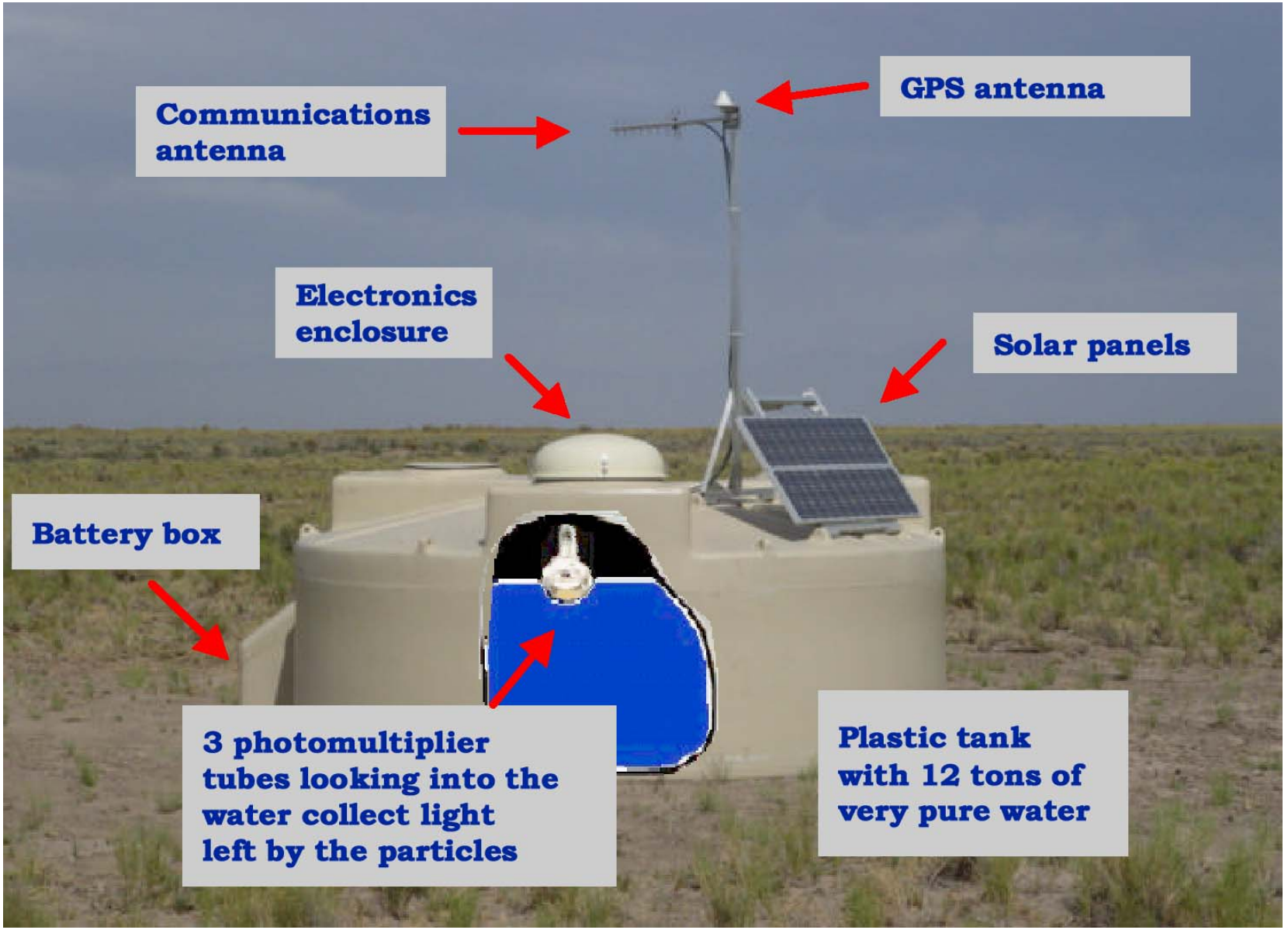
1600 surface detector stations: water-Cherenkov tanks (triangular grid of 1.5 km)

4 fluorescence detectors (24 telescopes in total)

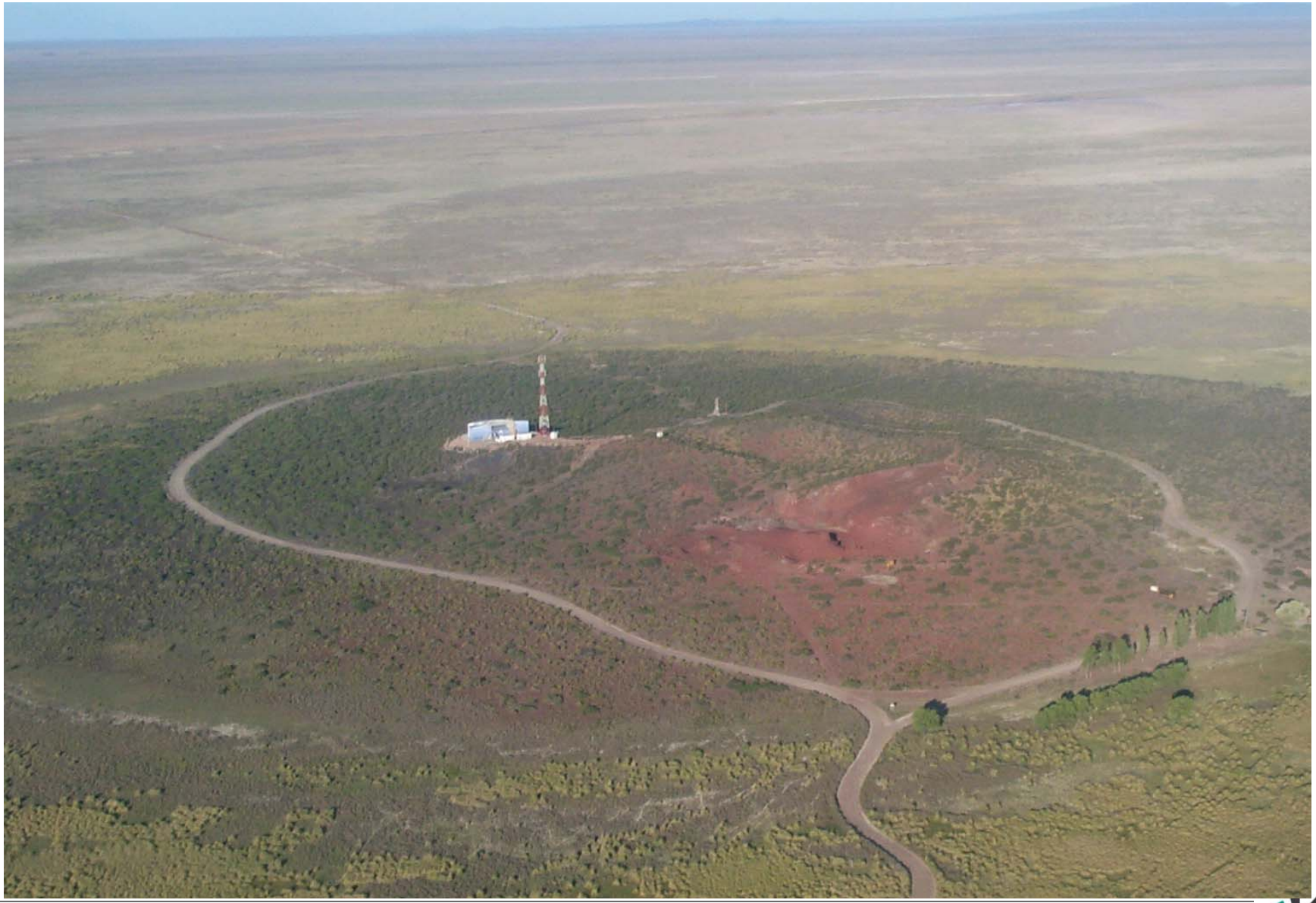
2 laser stations
balloon station

Surface array in the Argentinean Pampa

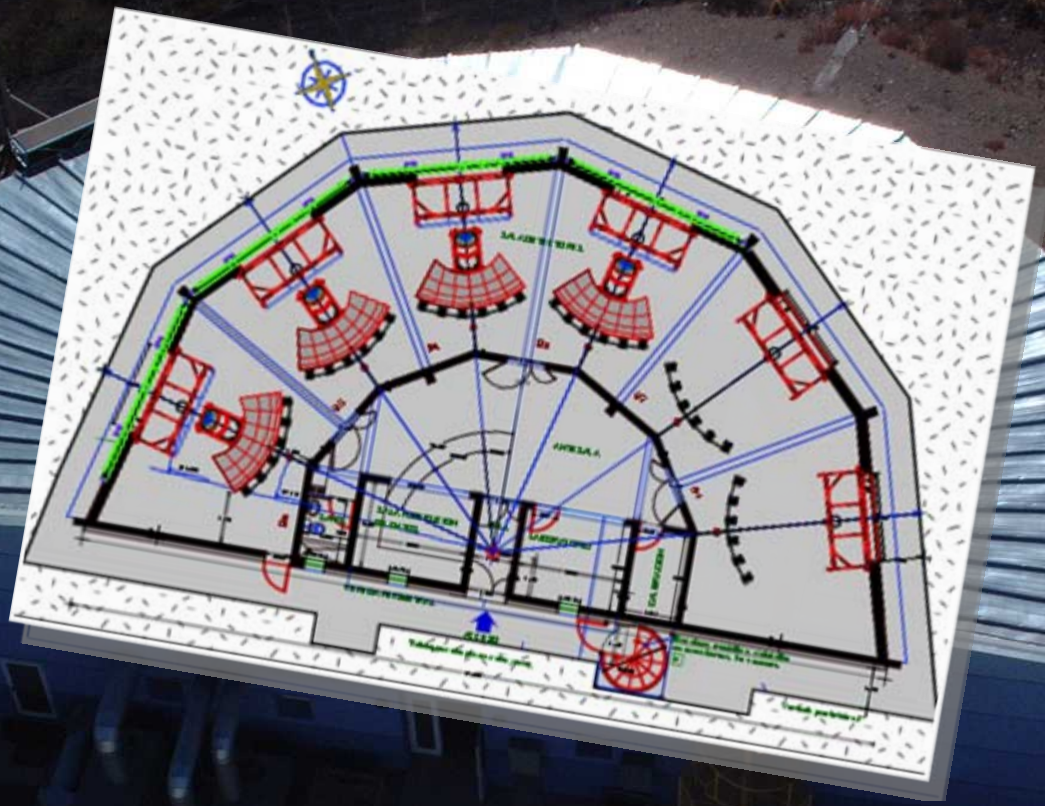
Water Cherenkov Detector



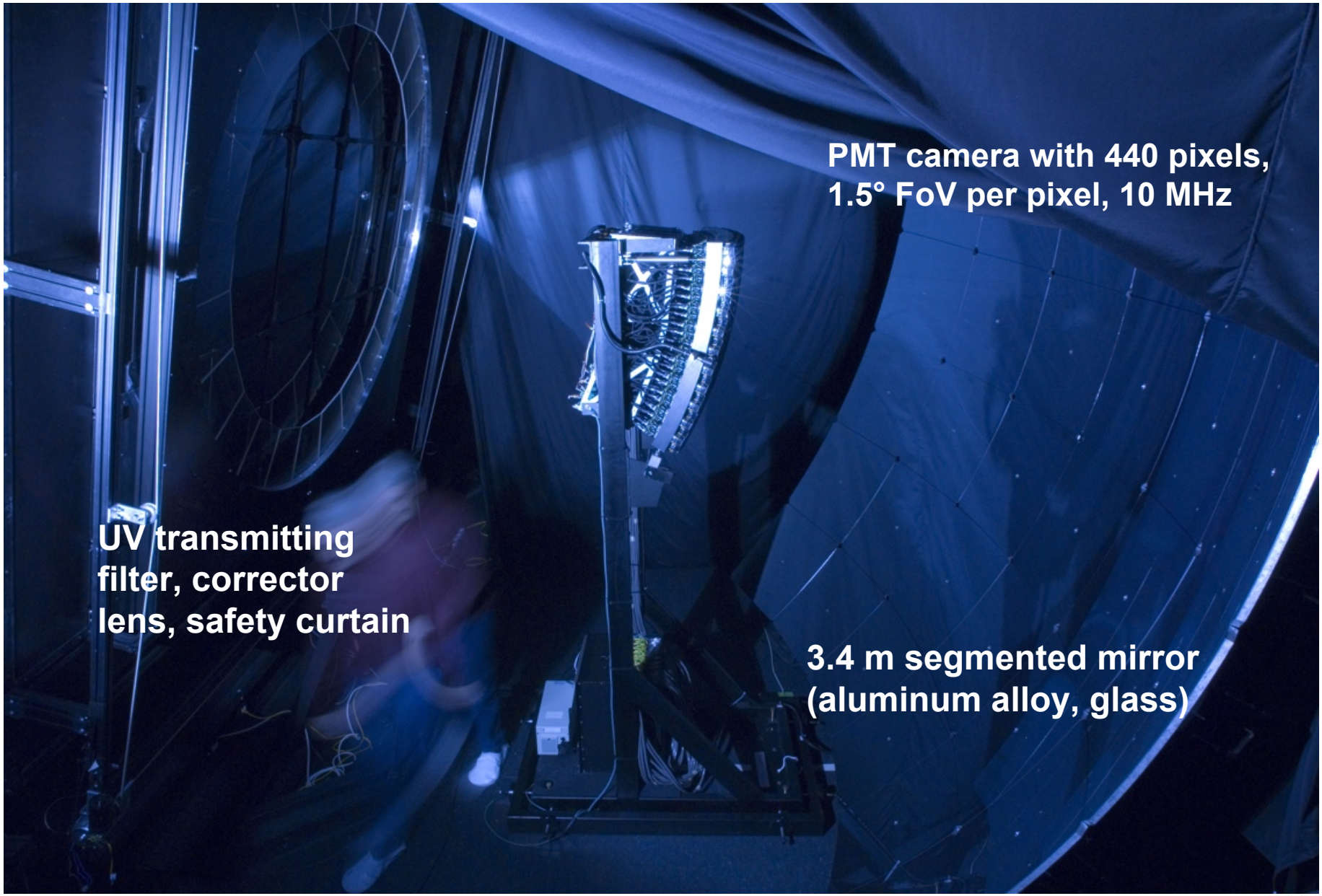
Fluorescence Telescopes



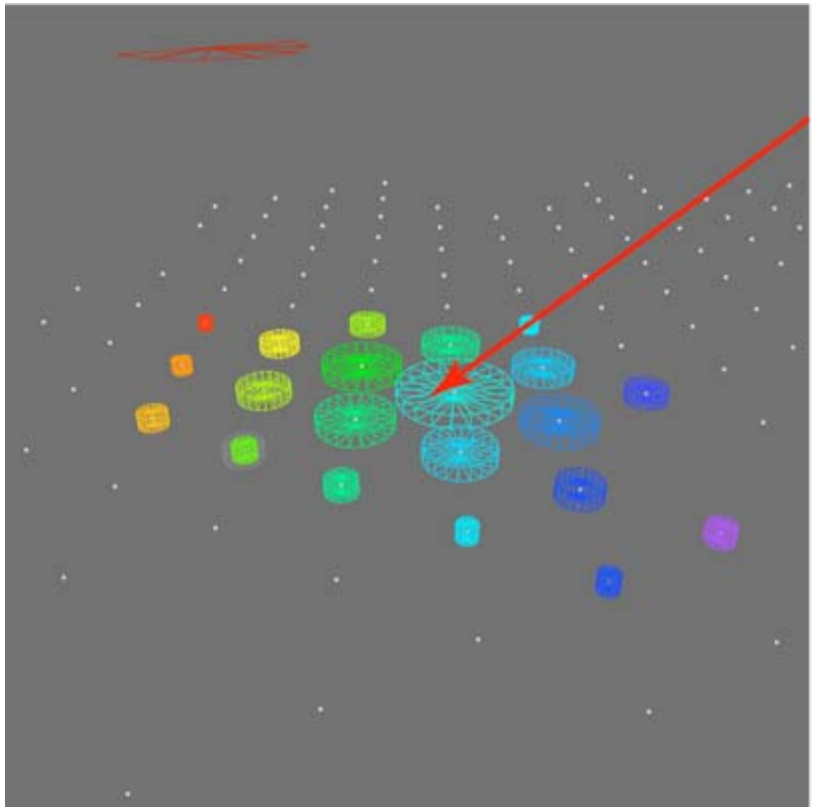
six telescopes each viewing 30° by 30°



One of 24 fluorescence telescopes



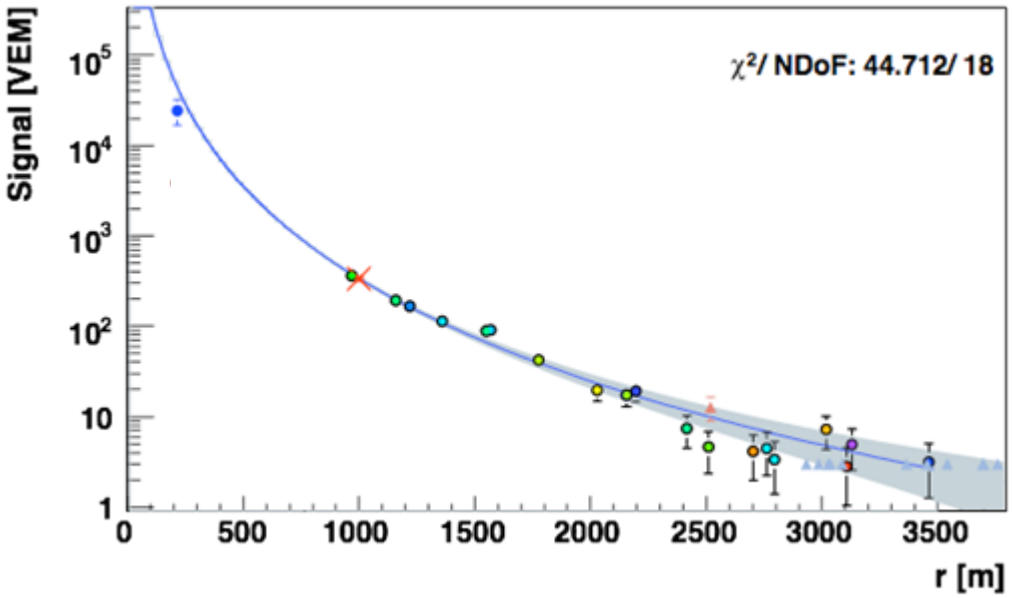
Surface detector events



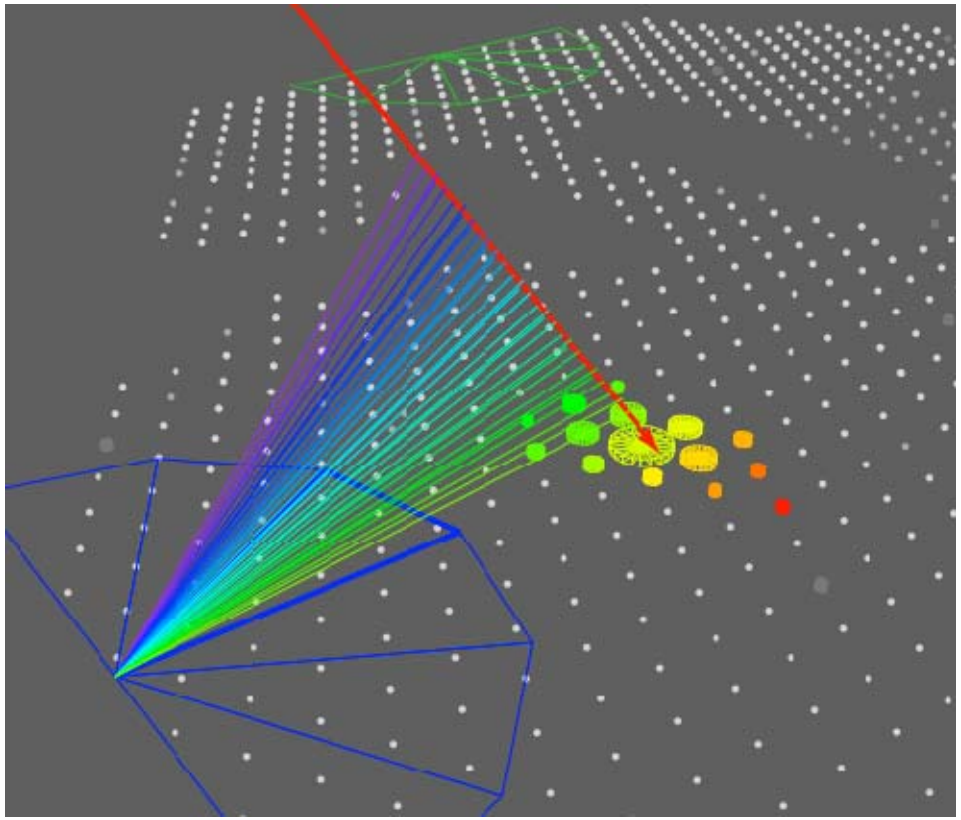
More than 650,000 events
(T5 trigger, used in analysis)

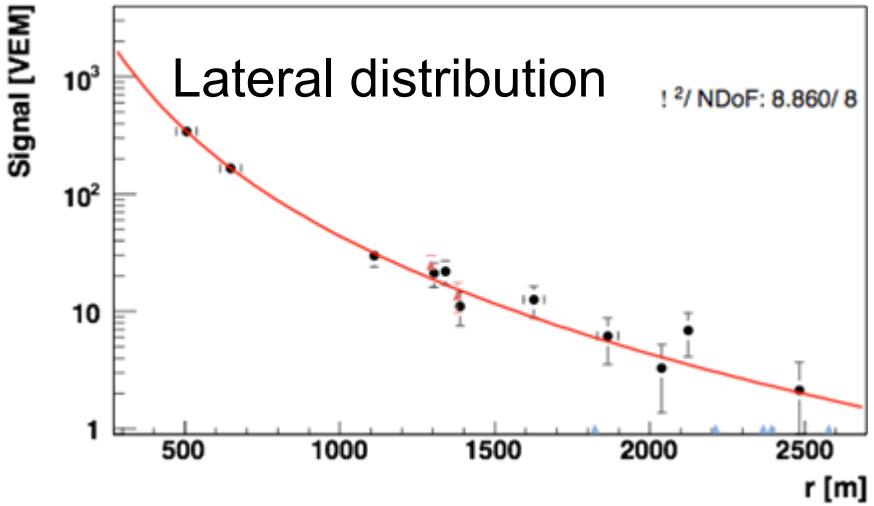
Tank signal in units
of the signal of
a vertical muon

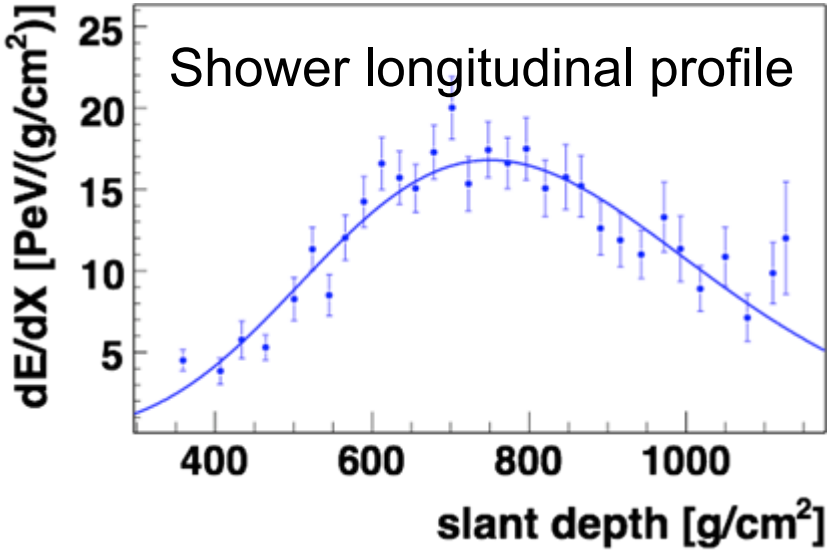
Example: E > 10^{20} eV, θ ≈ 45°



Golden hybrid events

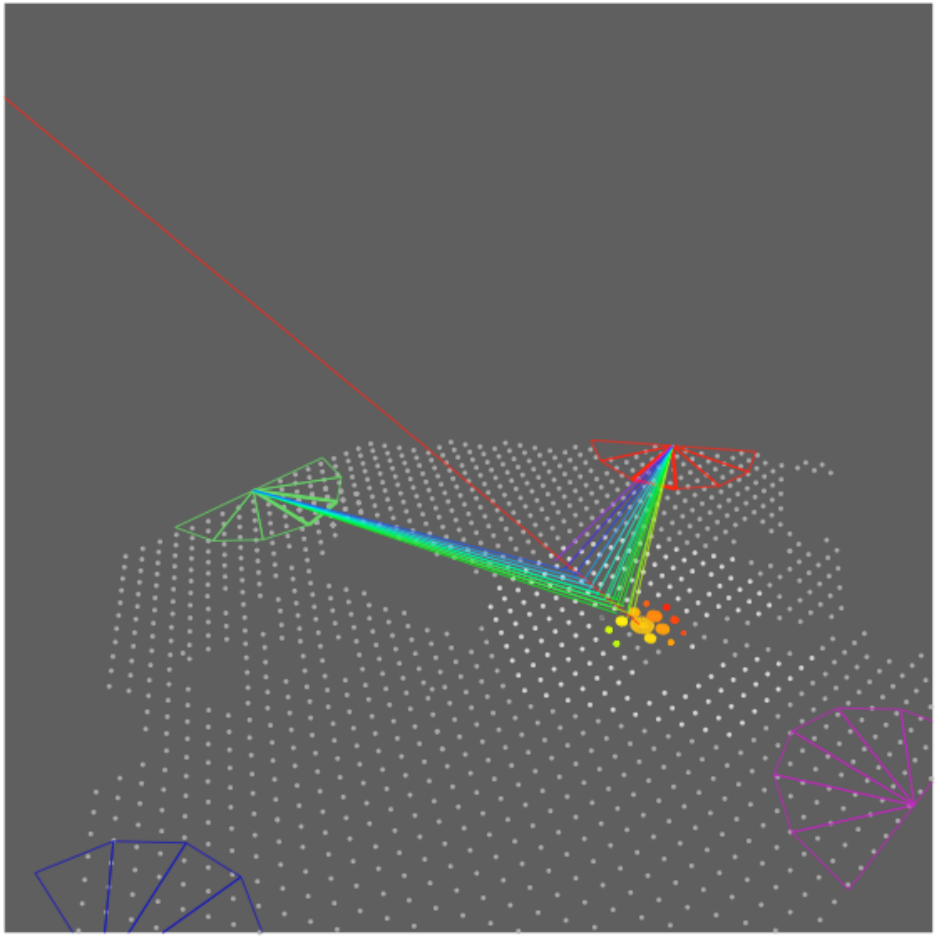




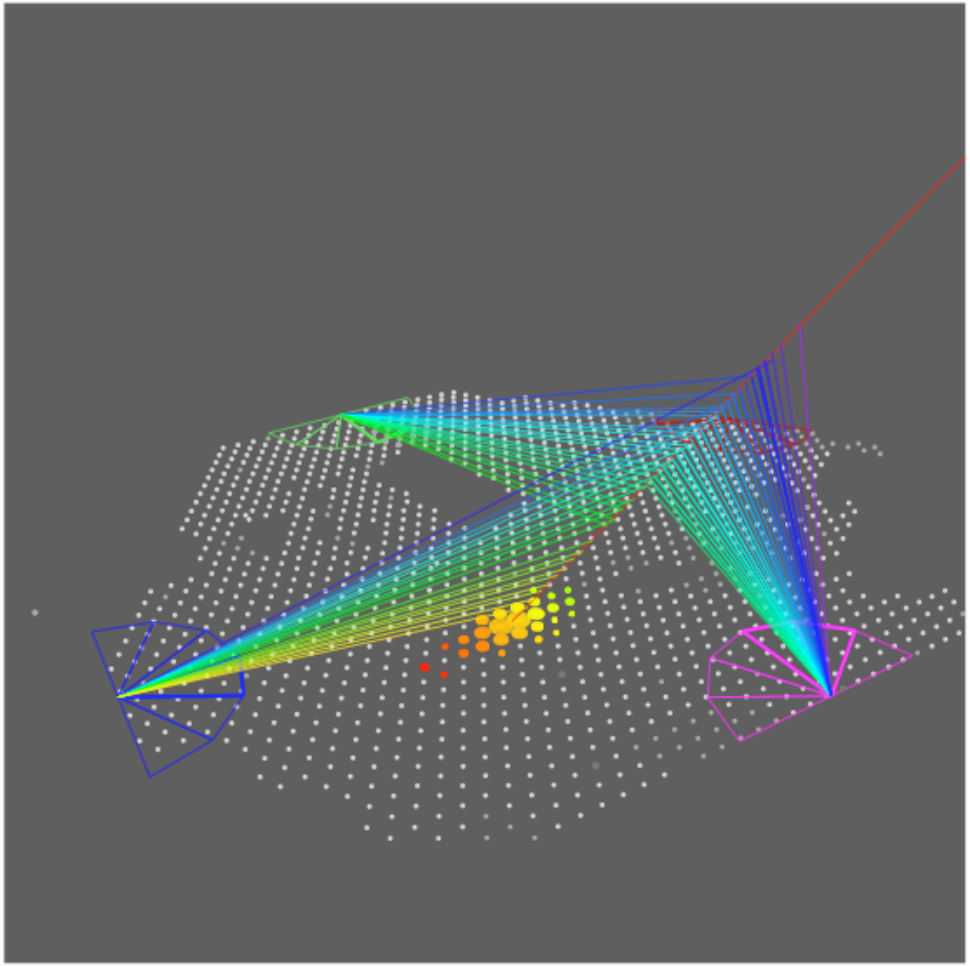


Hybrid events ~120,000
Golden hybrid events ~ 15,000

Other types of Auger events

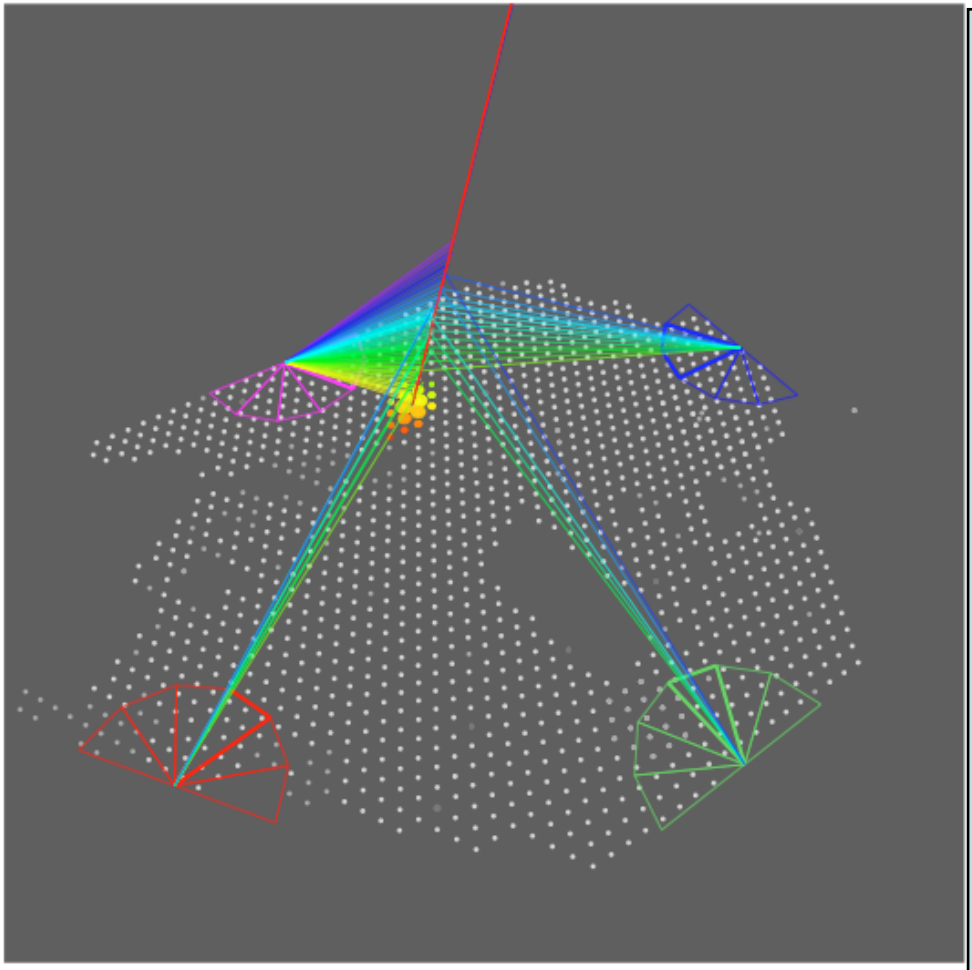


Event 200718905882 (9.7.2007)

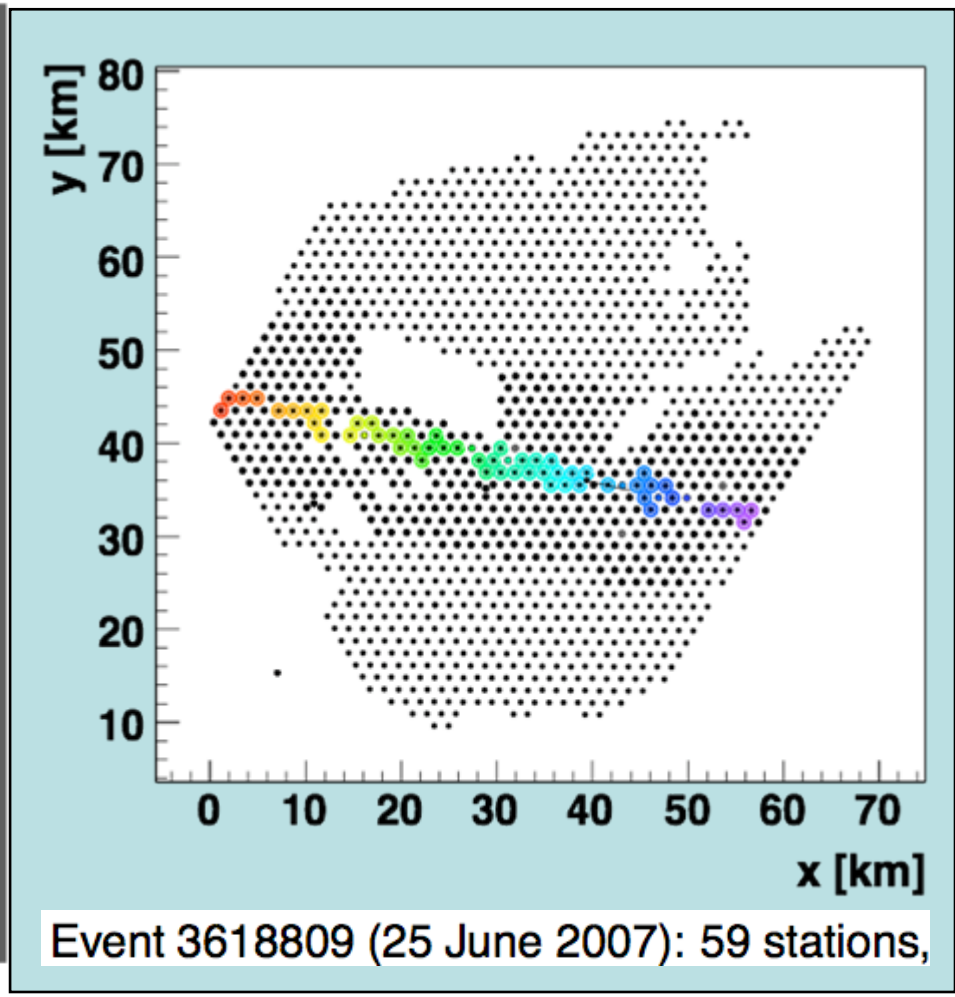


Event 200716104390 (11.6.2007)

Other types of Auger events

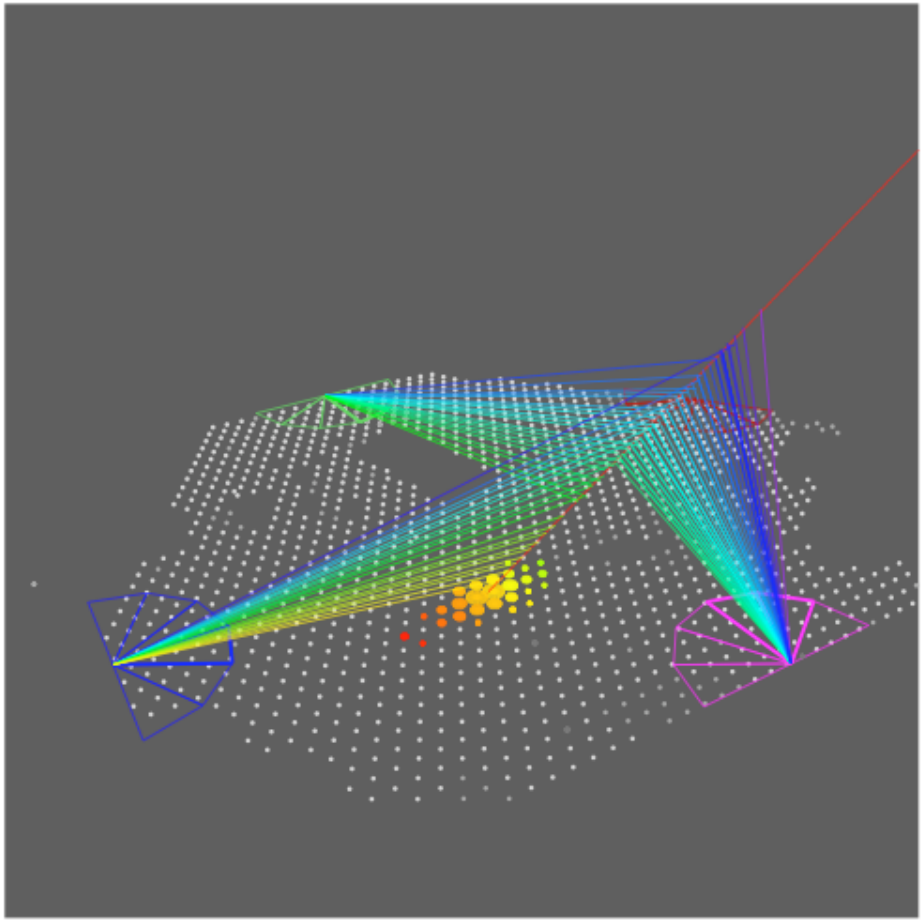


Event 200717001509 (19.6.2007)



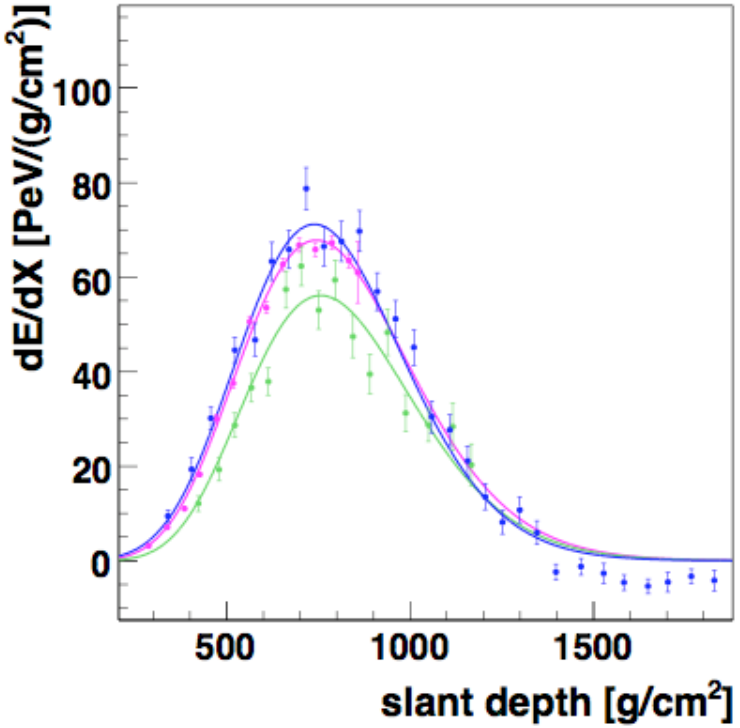
Event 3618809 (25 June 2007): 59 stations,

Golden hybrid events: many cross checks possible

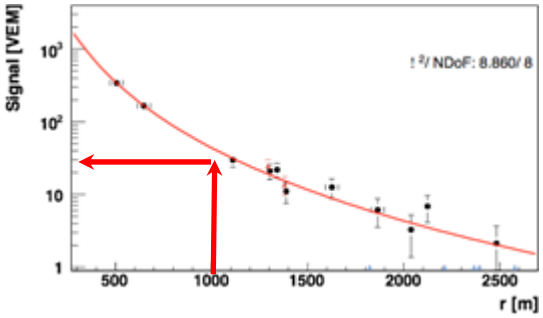


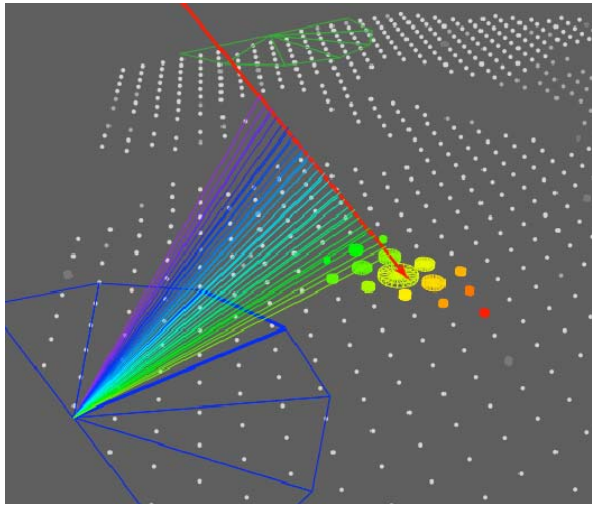
Event 200716104390 (11.6.2007)

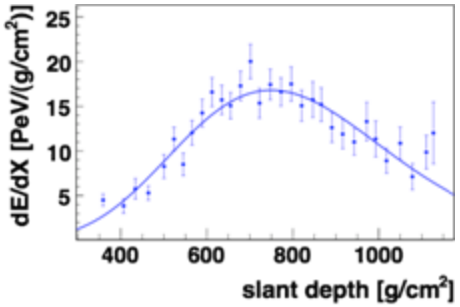
Independent profile reconstuctions



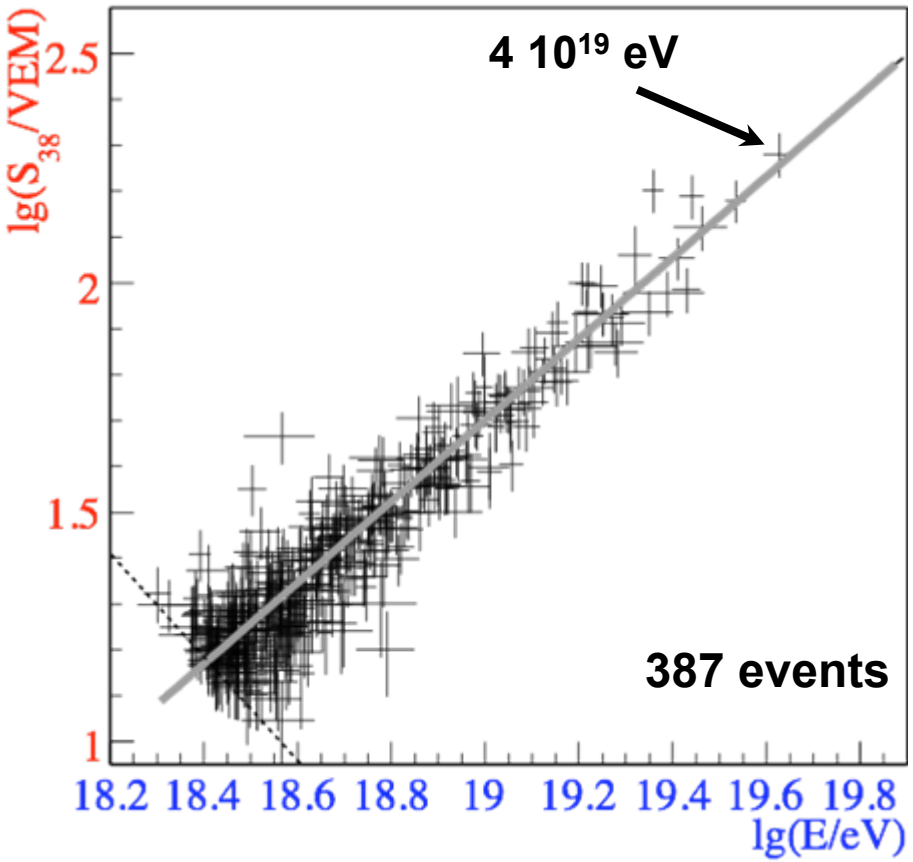
Energy calibration of surface detector by Hybrid events







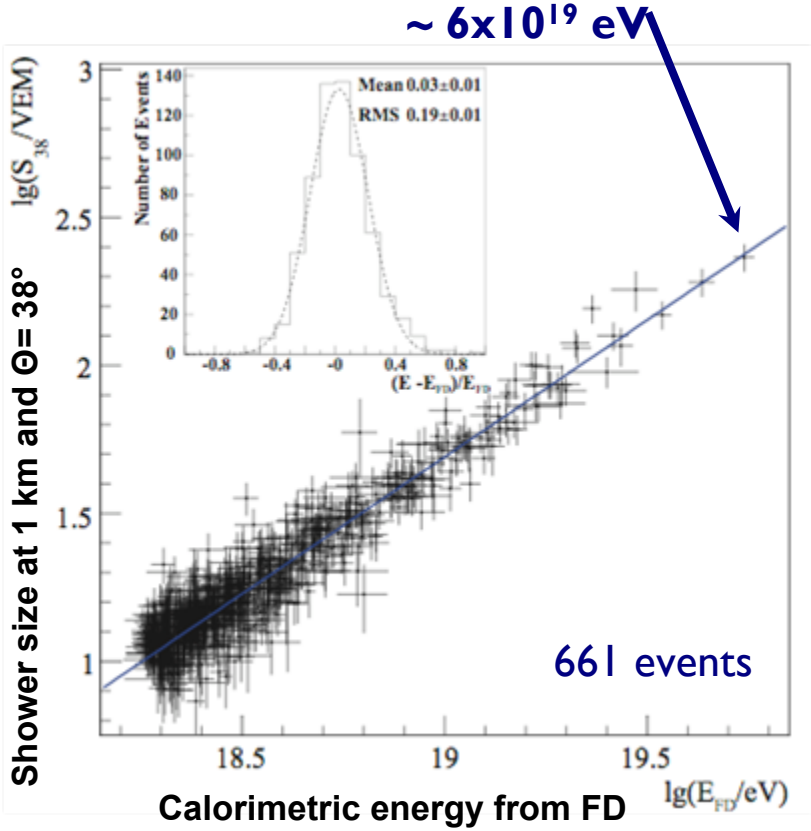
Shower size at 1000m and θ=38°

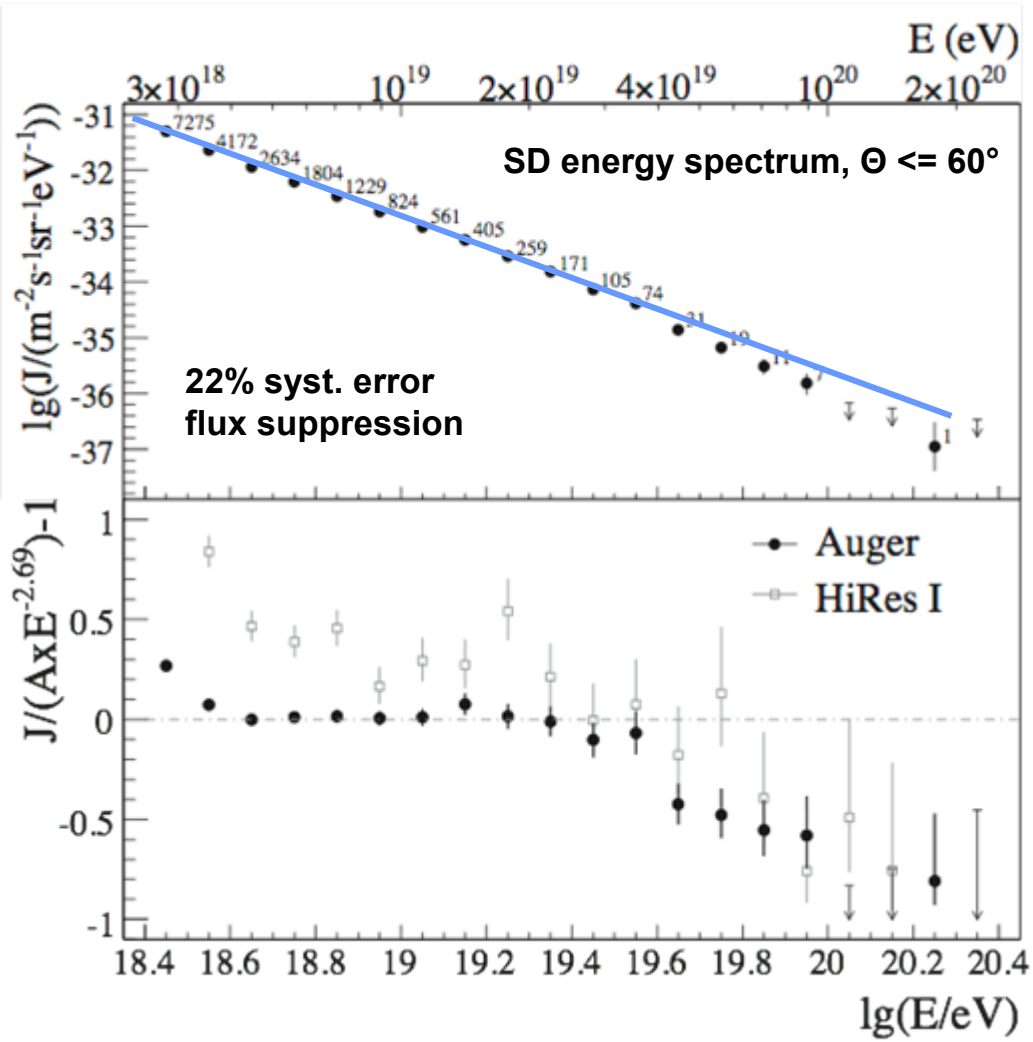


Fluorescence detector energy

$$E_{\mathrm{prim}} = f_{\mathrm{corr}} \cdot \int \frac{\mathrm{d}E_{\mathrm{ion}}}{\mathrm{d}X}\,\mathrm{d}X$$

Energy spectrum





Data: 1 Jan 2004 - 31 Aug 2007

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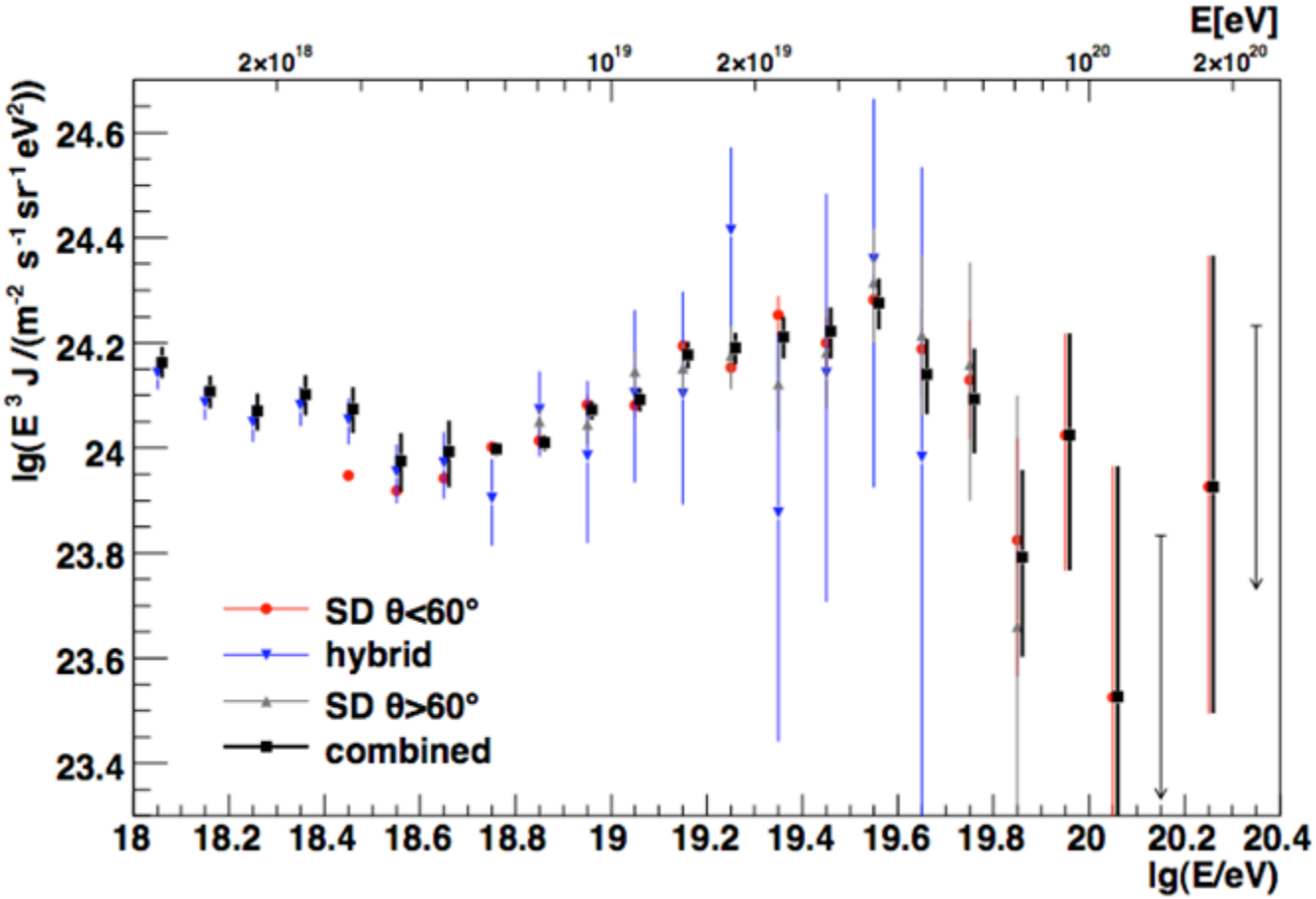
Energy spectrum: Other methods



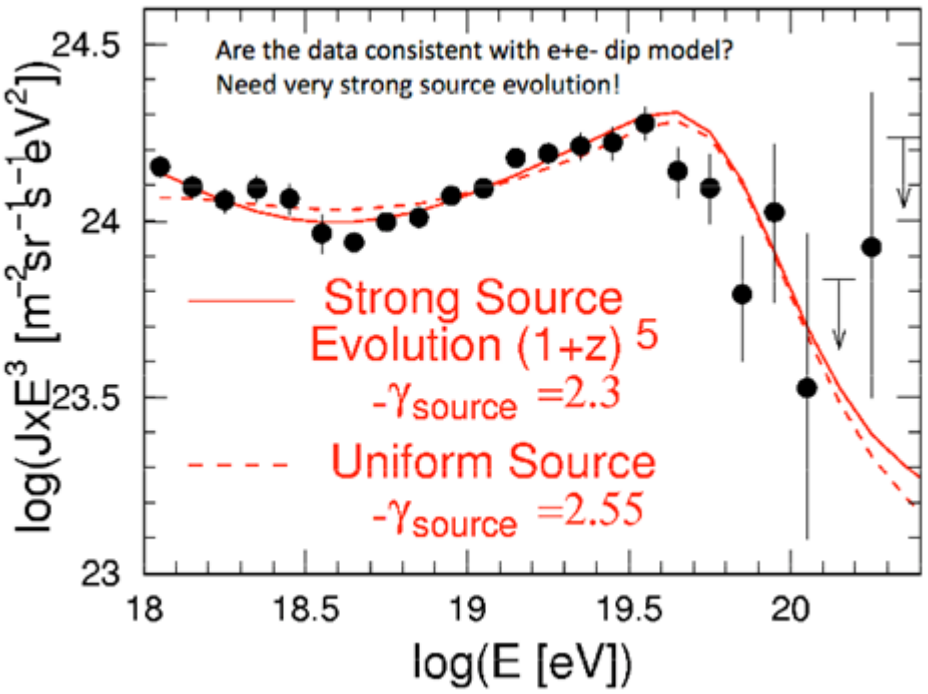
Transition from galactic to extragalactic cosmic ray sources?

Greisen-Zatsepin-Kuzmin (GZK) cutoff?

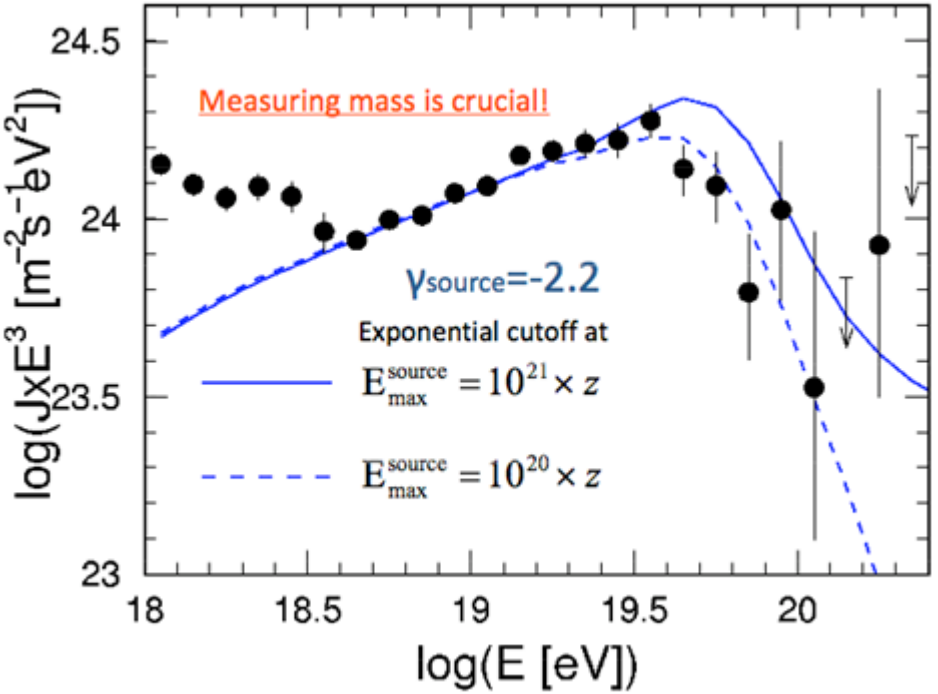
Comparison with GZK suppression models

? Observed flux suppression is due entirely to GZK effect
? Observed flux suppression is signature of maximum acceleration energy
? Observed flux suppression is due to both source cutoff and GZK effect

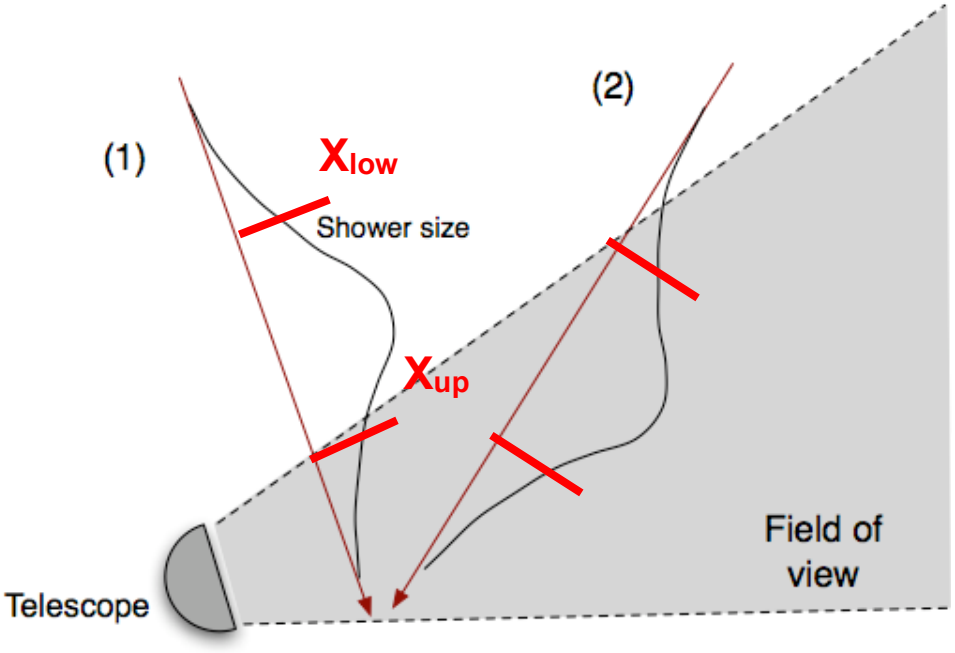
Pure proton model
(Berezinsky et al.)



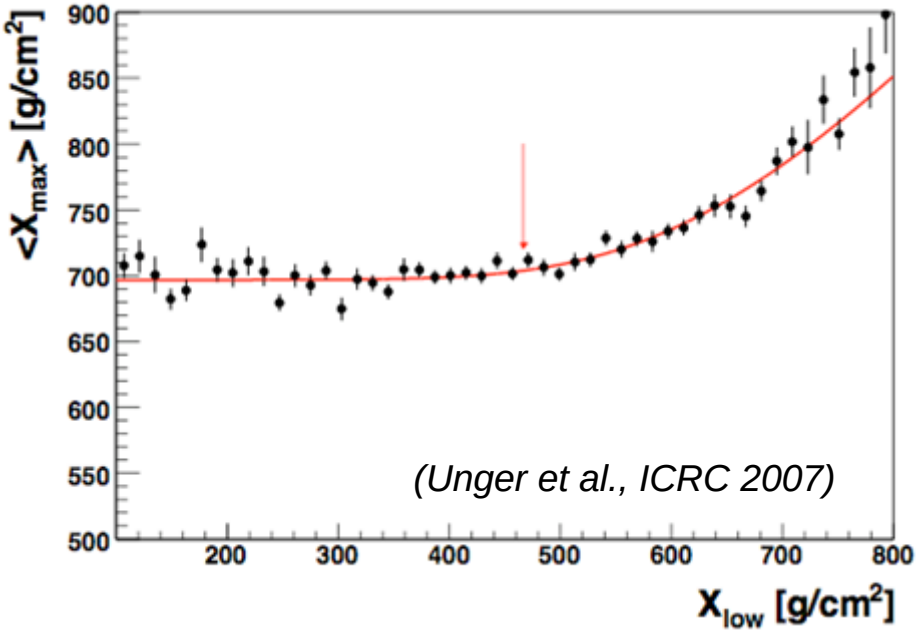
Mixed composition model
(Allard et al., Hillas)



Composition: measurement of longitudinal profile

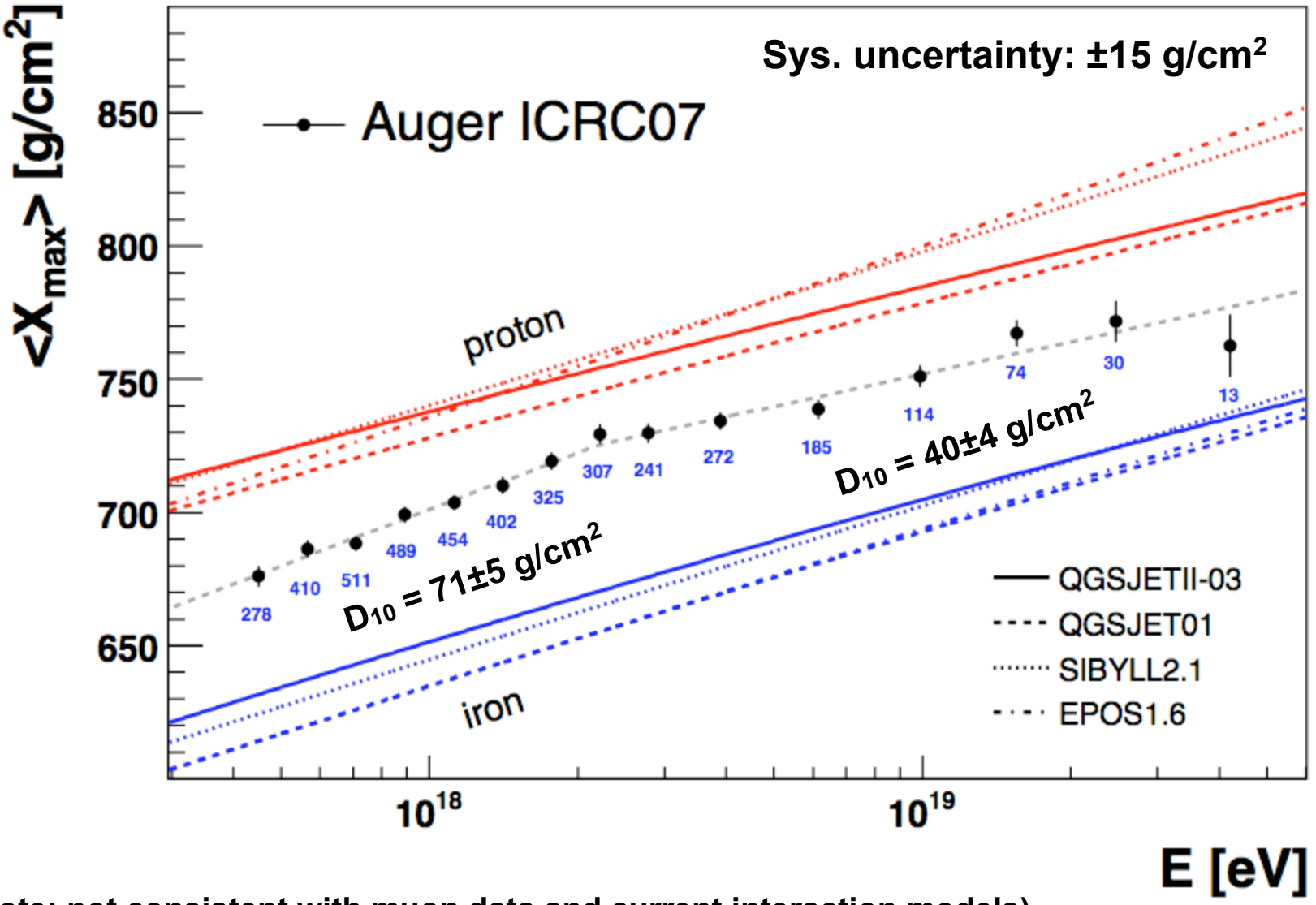


Field of view bias needs to be accounted for



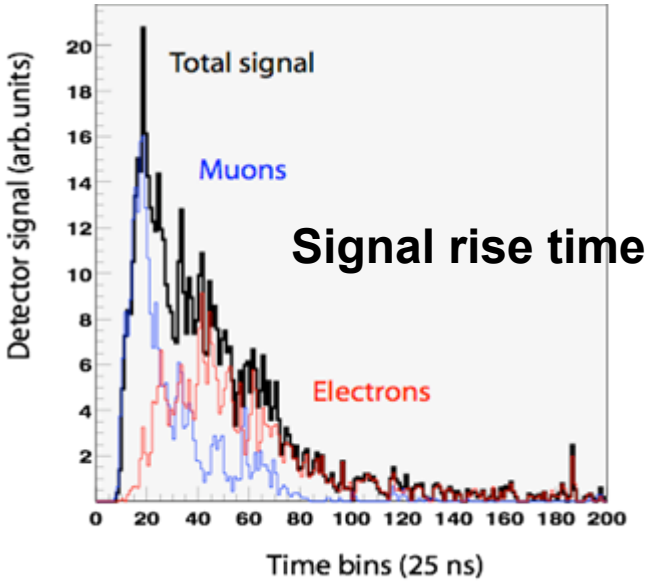
X_{low}, X_{up} are determined form data, no simulation needed

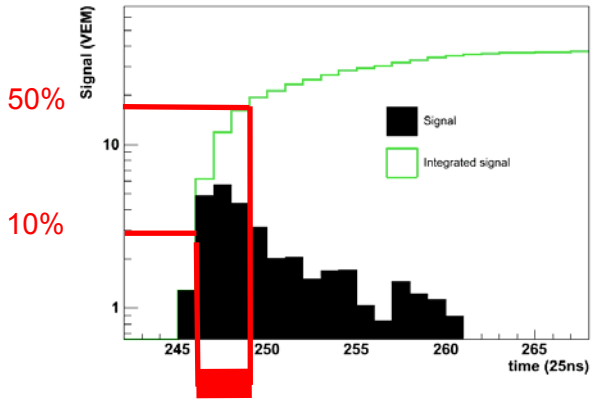
Composition: mean depth of shower maximum



(Note: not consistent with muon data and current interaction models)

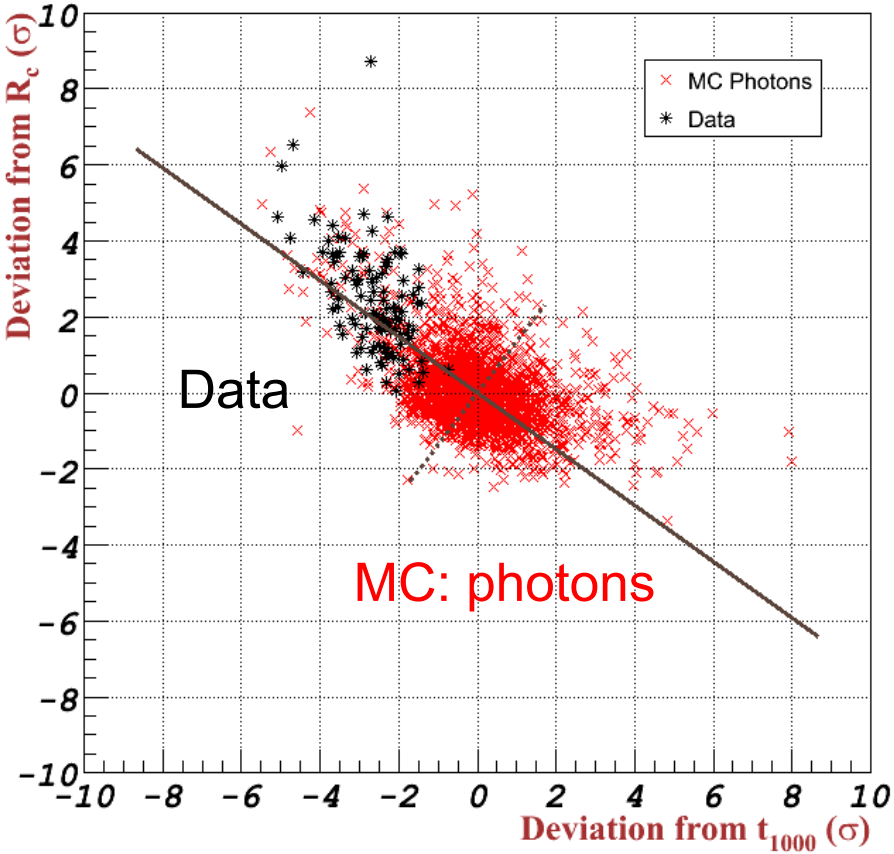
Photon limit: using surface detector data





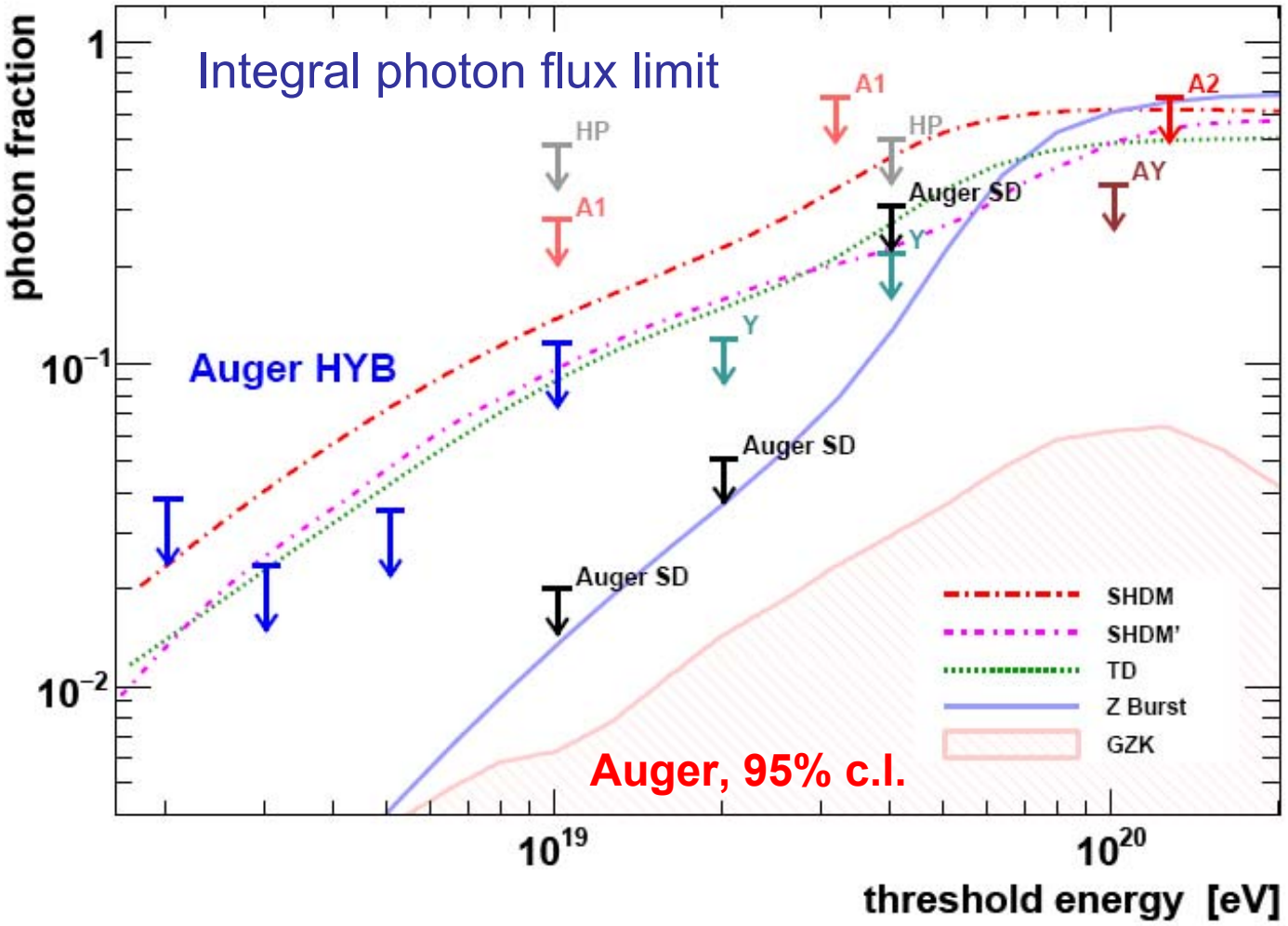
$t_{1/2}$ = 81.39 ns

Shower front curvature



Rise time

Limit on fraction of photons in UHECR flux



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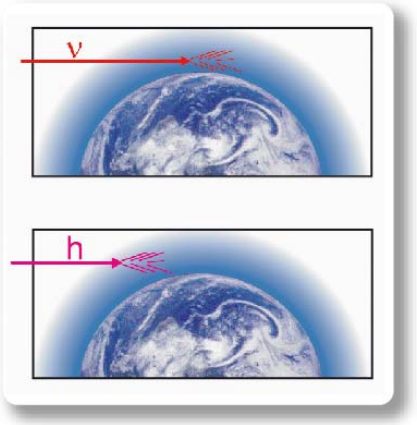
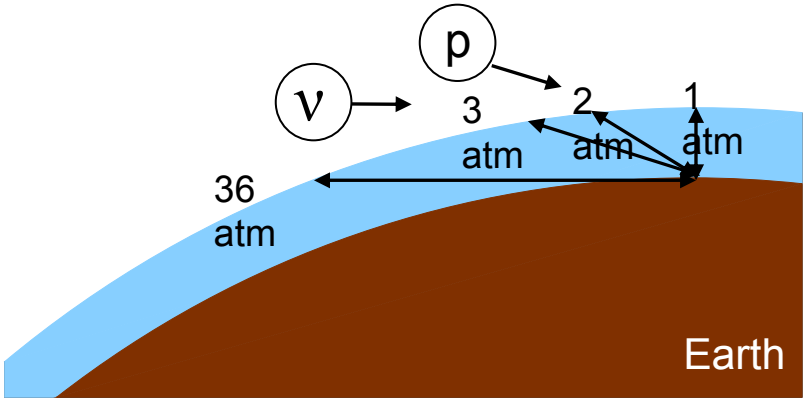
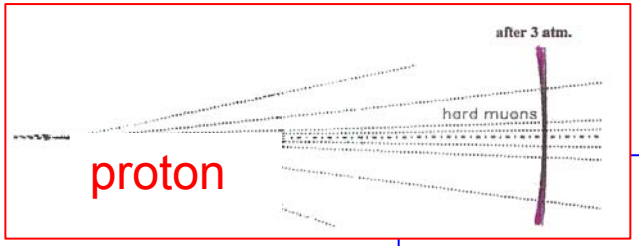
Many exotic source scenarios excluded

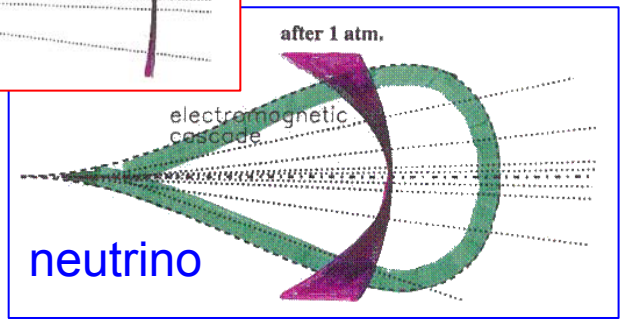
Neutrino limit: horizontal air showers



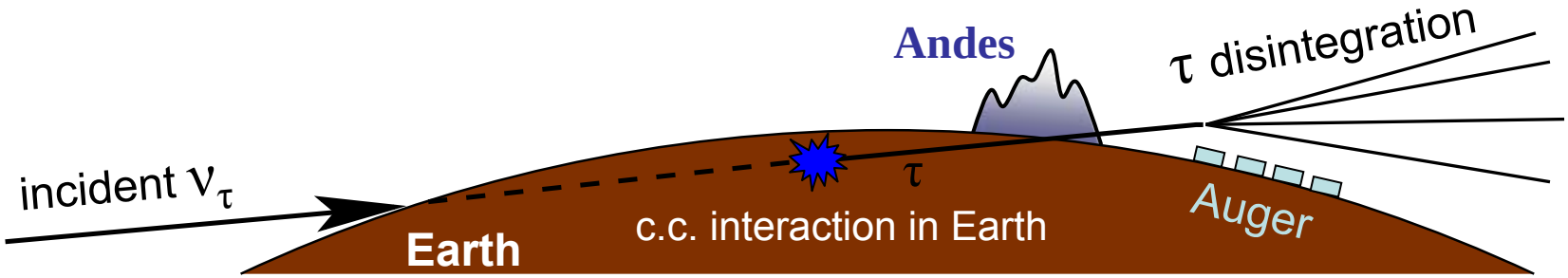
nearly horizontal air showers from extremely high energy ν_e or ν_μ neutrinos





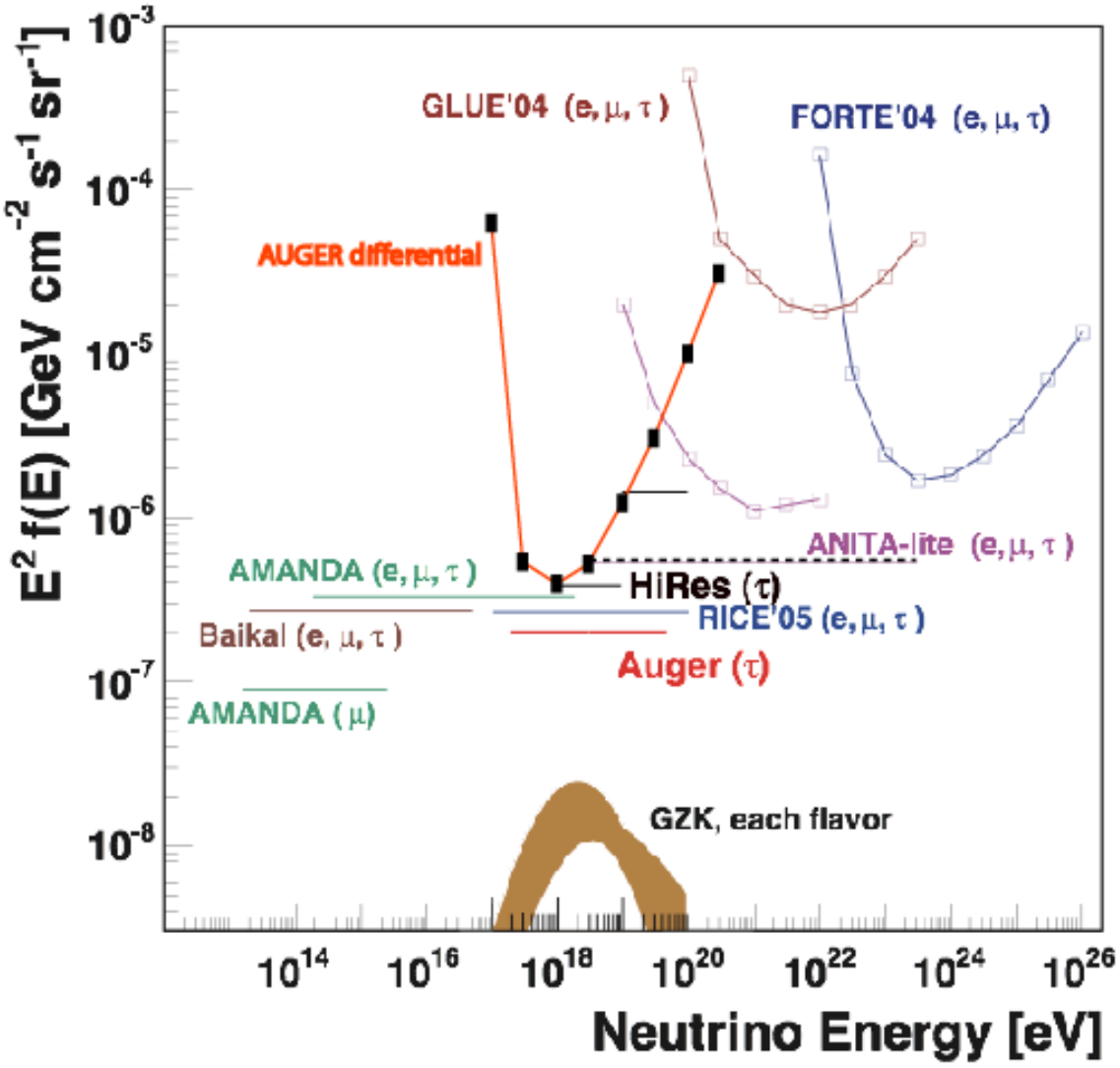


air showers from skimming ν_τ neutrinos



Flux limits for neutrinos

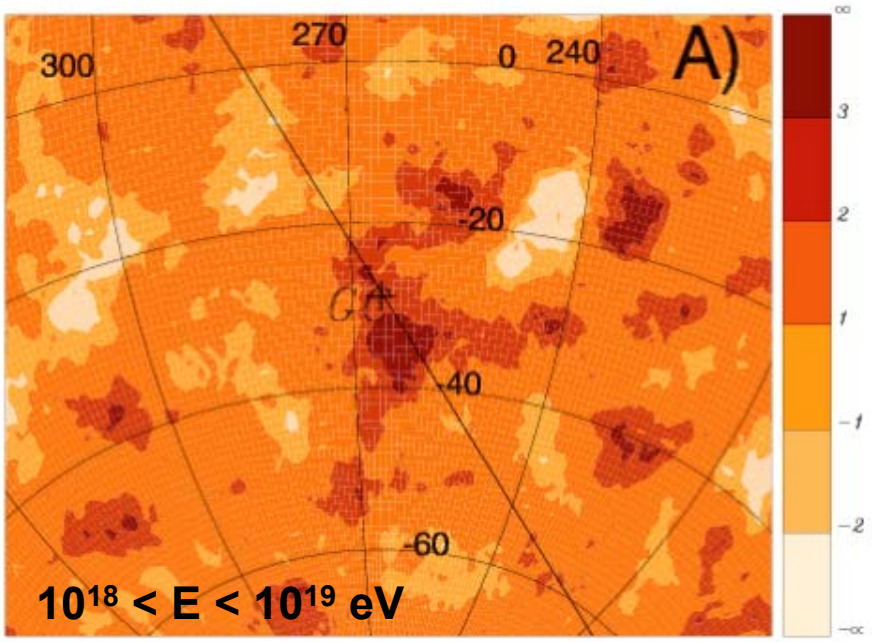
Use horizontal showers of SD



Data: 1 Jan 2004 – 31 Aug 2007
PRL 100 (2008) 211101

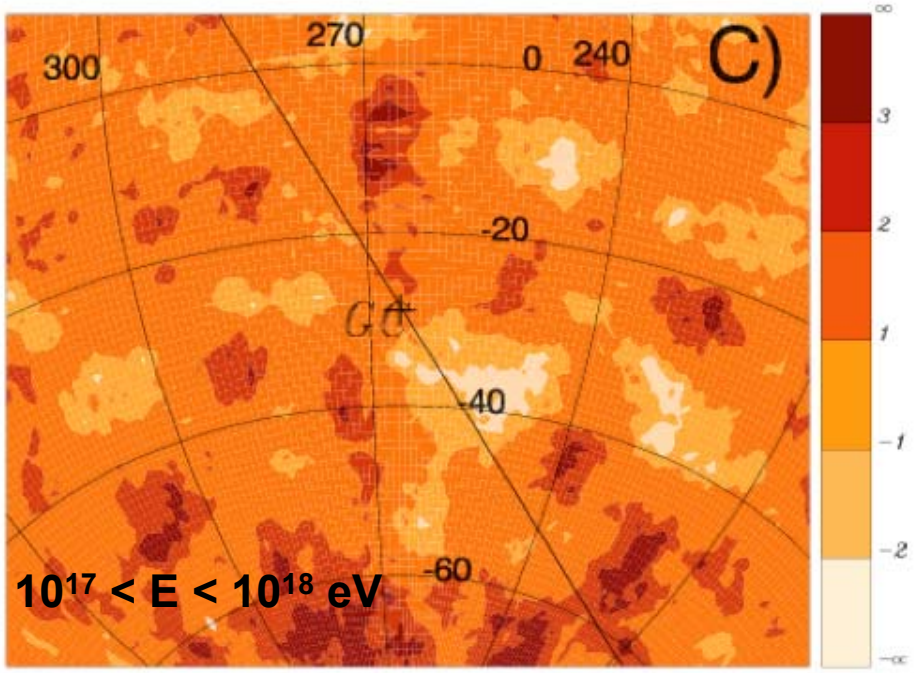
Arrival directions: Galactic center point source search

Significance plots



Dark red: ***more events than expected***
Light red: ***fewer events than expected***

AGASA: would have 16σ
SUGAR: would have 30σ in Auger



No confirmation of previous indications for excess from GC region

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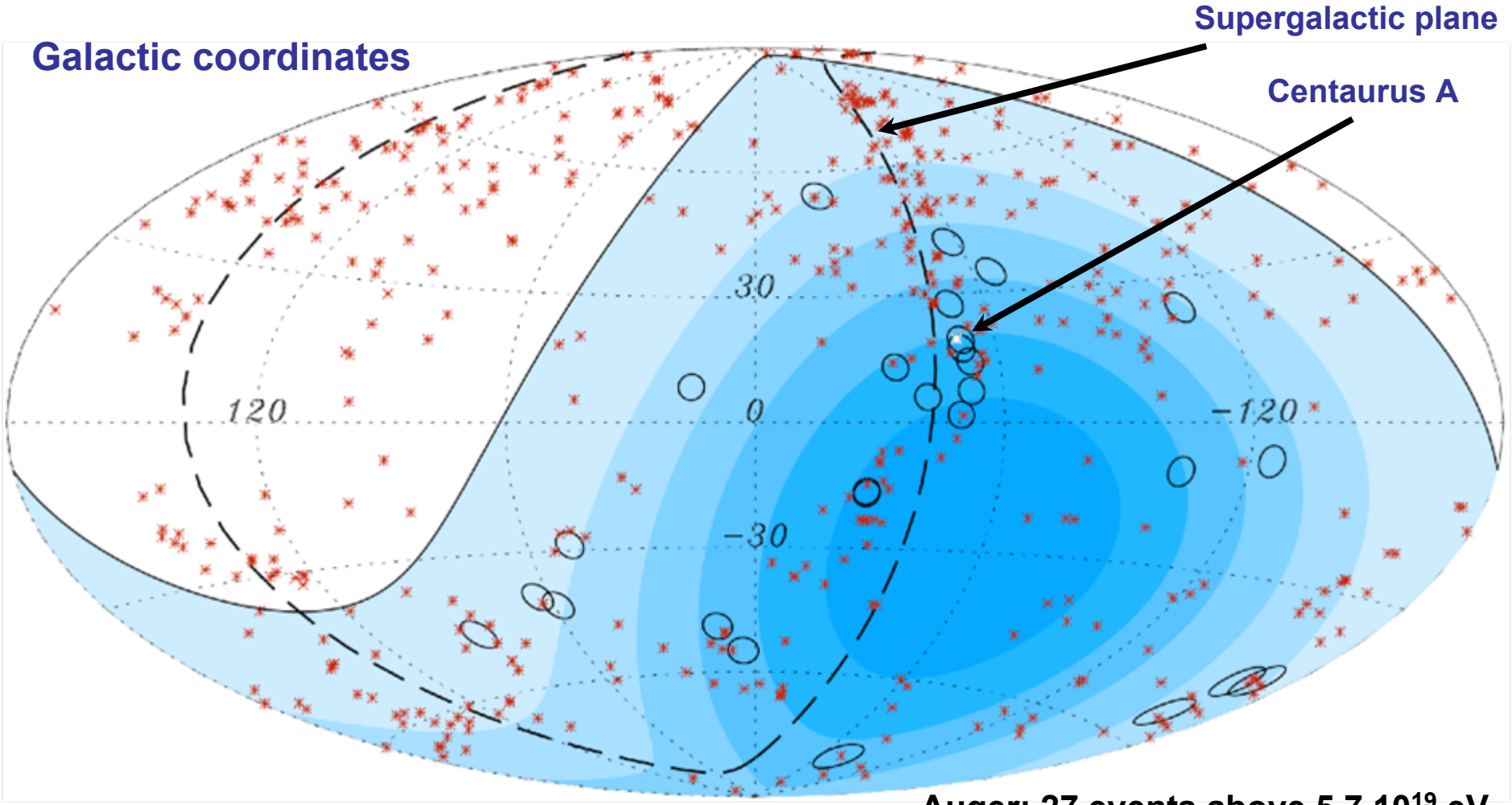
Anisotropy of ultra-high energy cosmic rays

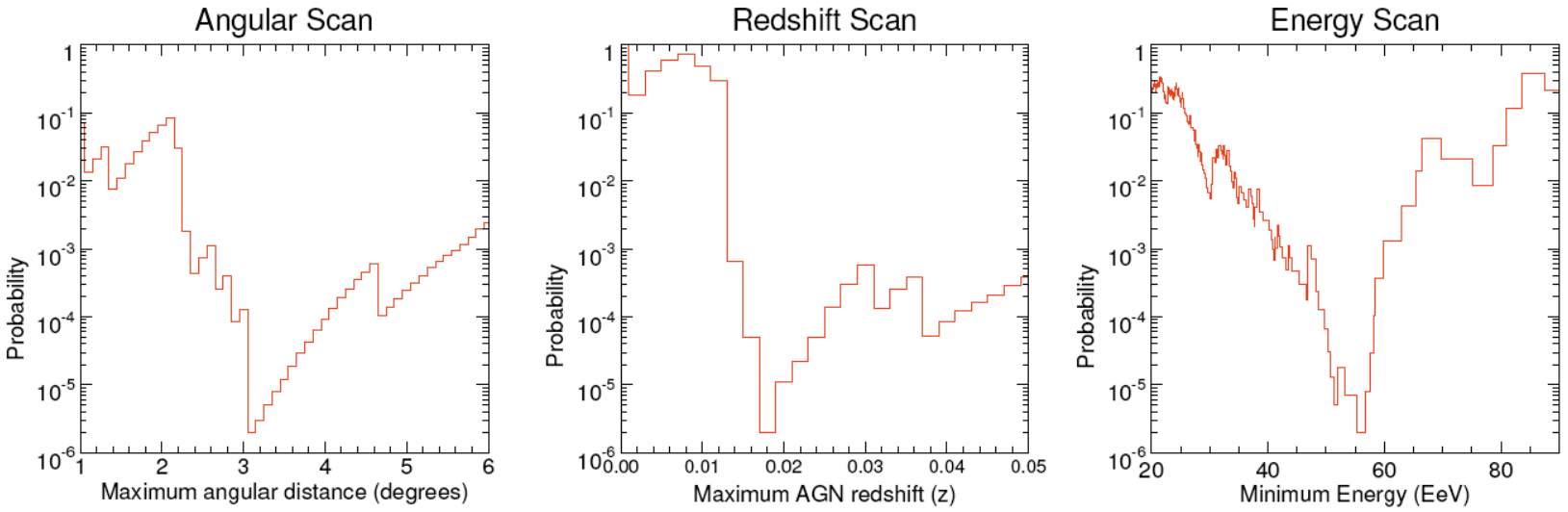


Veron-Cetty: 472 AGN (z< 0.018, ~75 Mpc)
318 in field of view of Auger

Auger: 27 events above 5.7 10^{19} eV,
20 correlated within 3.1°,
5.7 expected

Possible correlation with nearby AGNs ?

- 12th Veron-Cetty & Veron catalogue of AGN
- Data set: Jan1st, 2004 to May 27th, 2006, well-contained events
- Scan over angular distance, maximum redshift, energy threshold



Minimum: 12 out of 15 correlated with nearby AGNs (3.2 expected)

$\Delta\alpha = 3.1°$, $E_{min} = 5.6 \times 10^{19}$ eV, $z_{max} = 0.018$ (75 Mpc)

Uncorrected chance probability: $P \sim 2 \times 10^{-6}$

Science 318 (2007) 939
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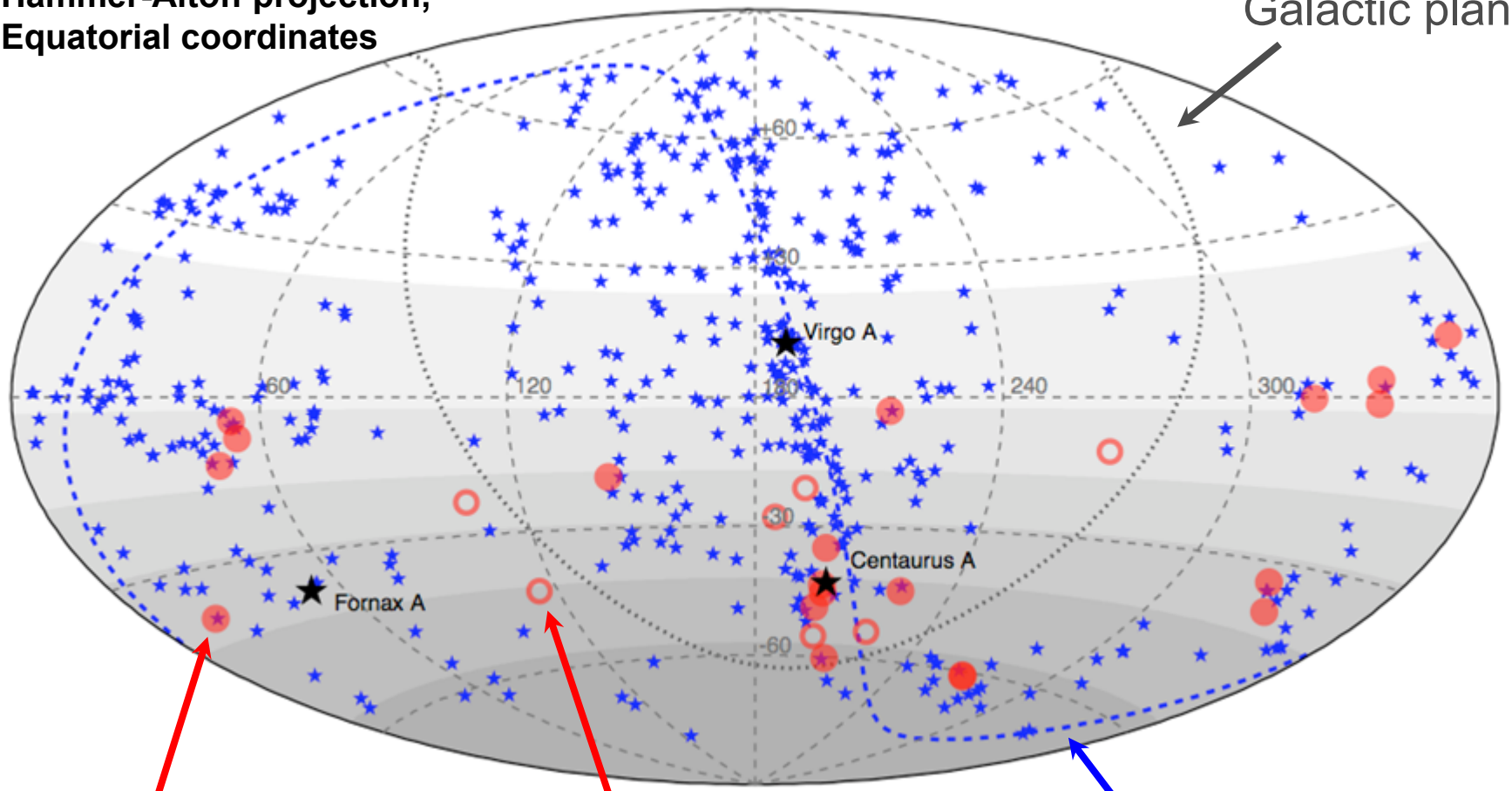
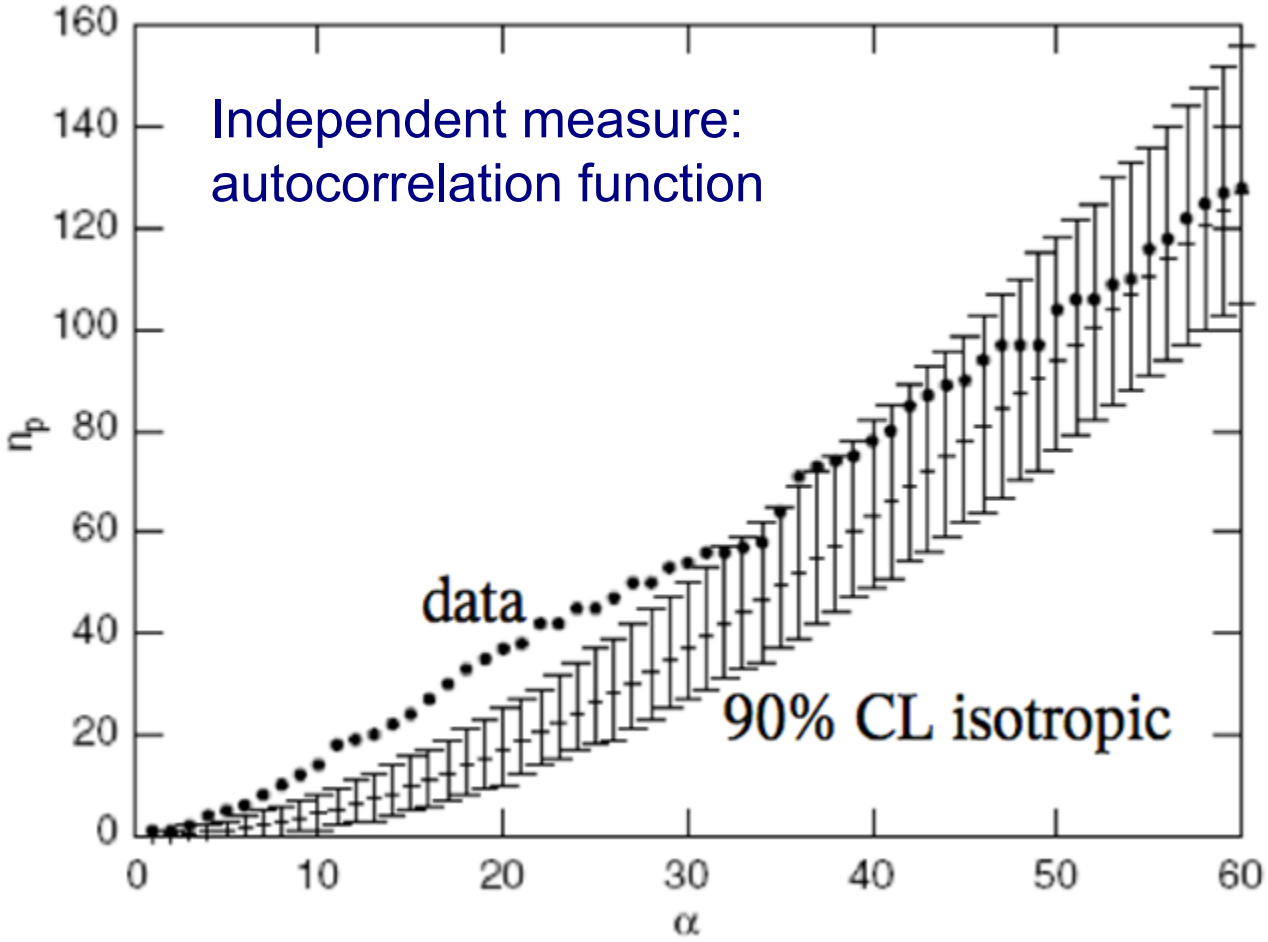
Anisotropy of ultra-high energy cosmic rays

Hammer-Aitoff projection,
Equatorial coordinates



Arrival direction distribution is anisotropic



Could it be that AGNs are indeed the sources?

Assumption: all AGNs of the VC catalogue have same injection power

Expectation: ~6 events from Virgo cluster, none observed
(excluded at 99% level for complete distribution)

(Gorbunov et al., arXiv:0711.4060 [astro-ph])

Possible interpretations:

- AGNs have different injection power (predicted by Biermann, Falcke et al.)
- Sub-class of AGNs are sources
- AGNs are not sources, sources are distributed similar to AGNs
- .....

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Note:

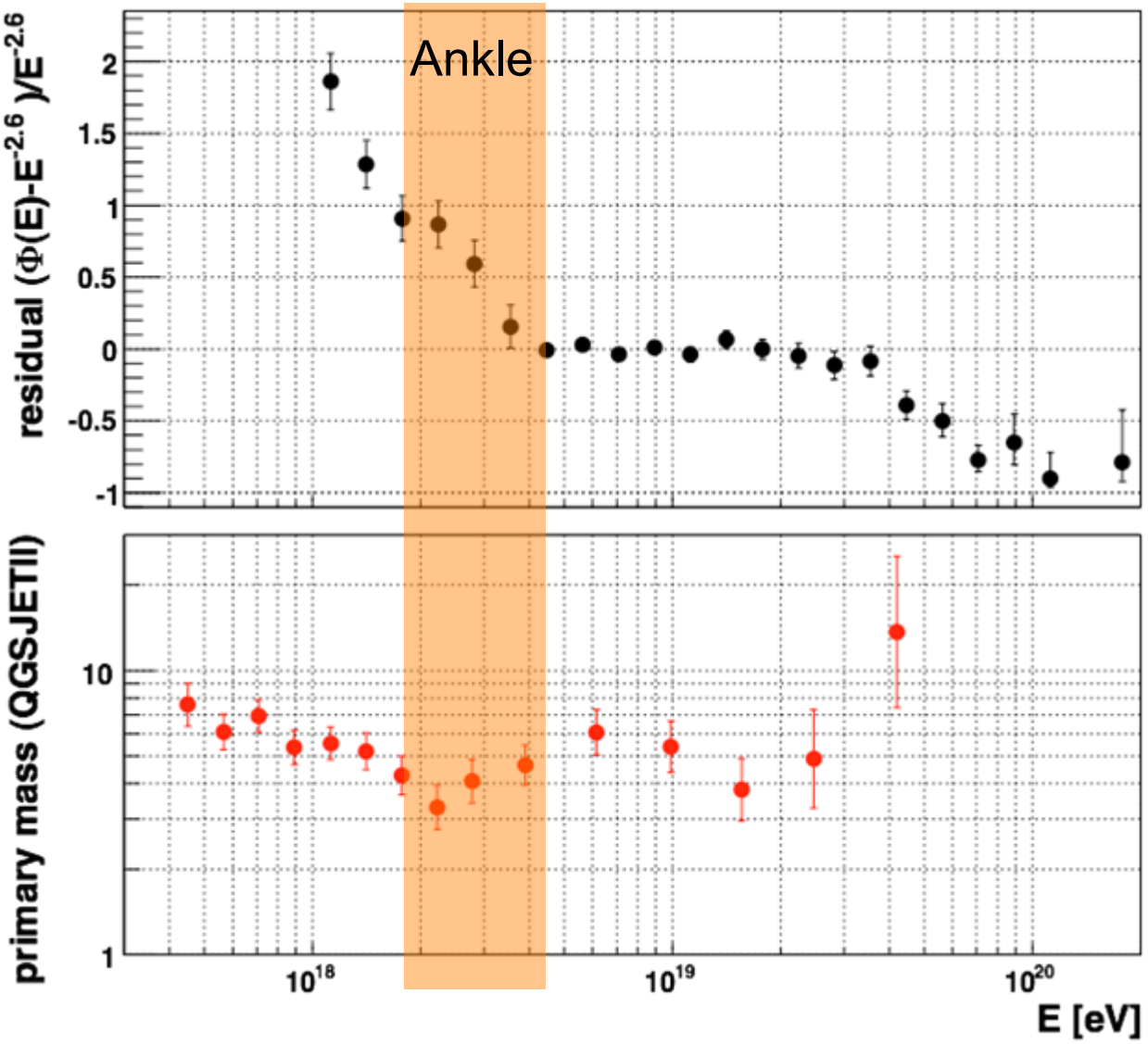
- AGNs are standard Seyfert galaxies (not very powerful)
- Anisotropy of distribution independent of source catalogue
- Correlation with supergalactic plane
- HiRes stereo data

(Stanev., arXiv:0805.1746 [astro-ph])

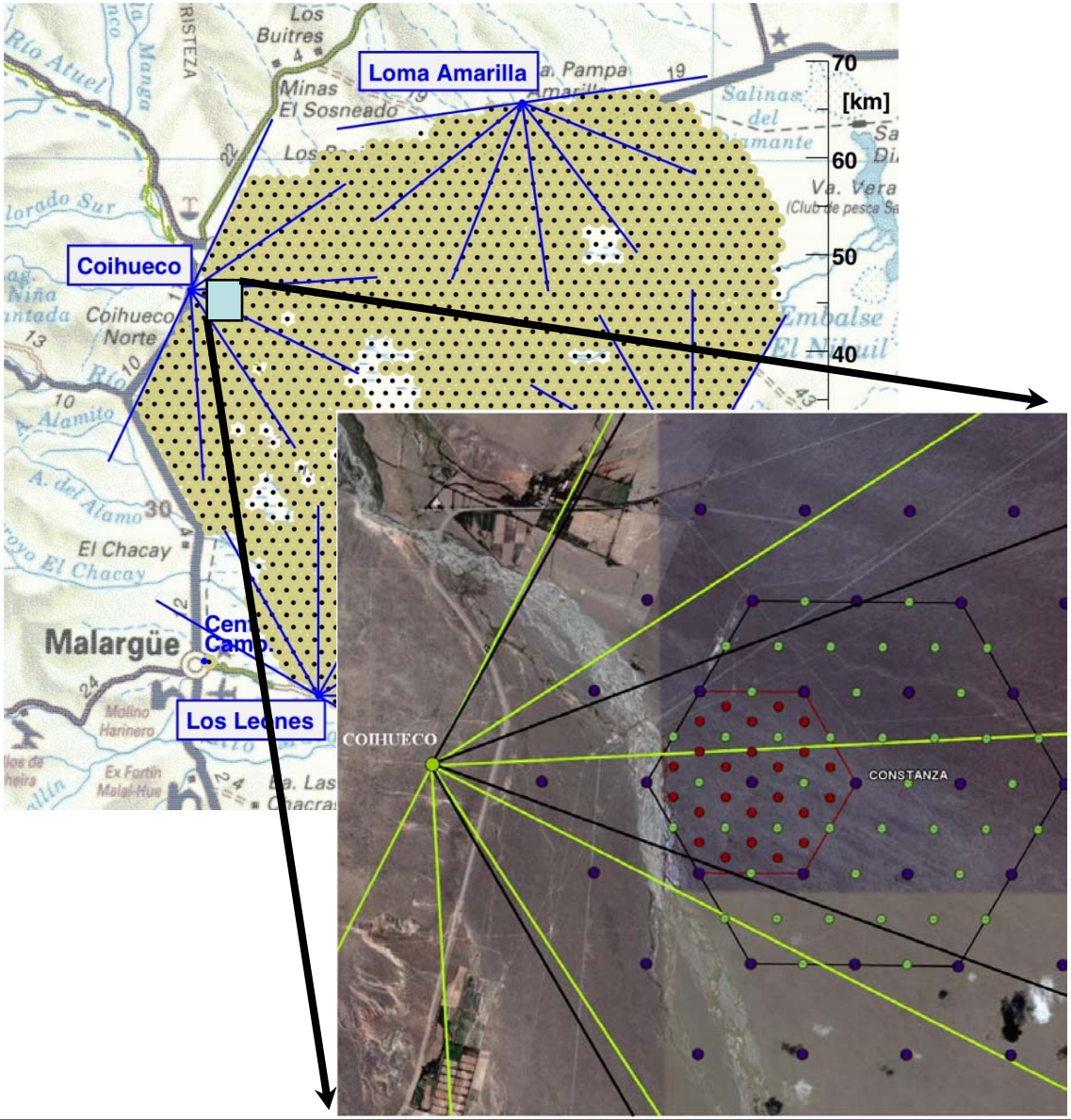
Auger Enhancements: investigating the ankle

Deviation from $E^{-2.6}$ flux

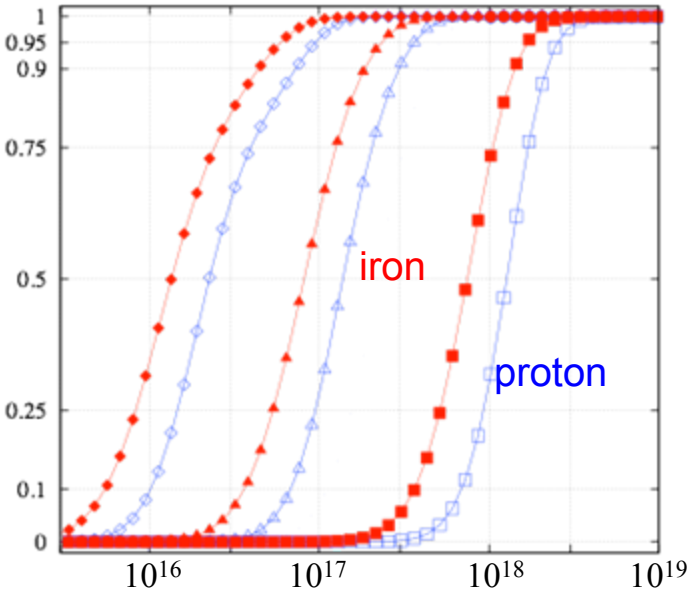
Mean mass number



Infill array of water Cherenkov detectors



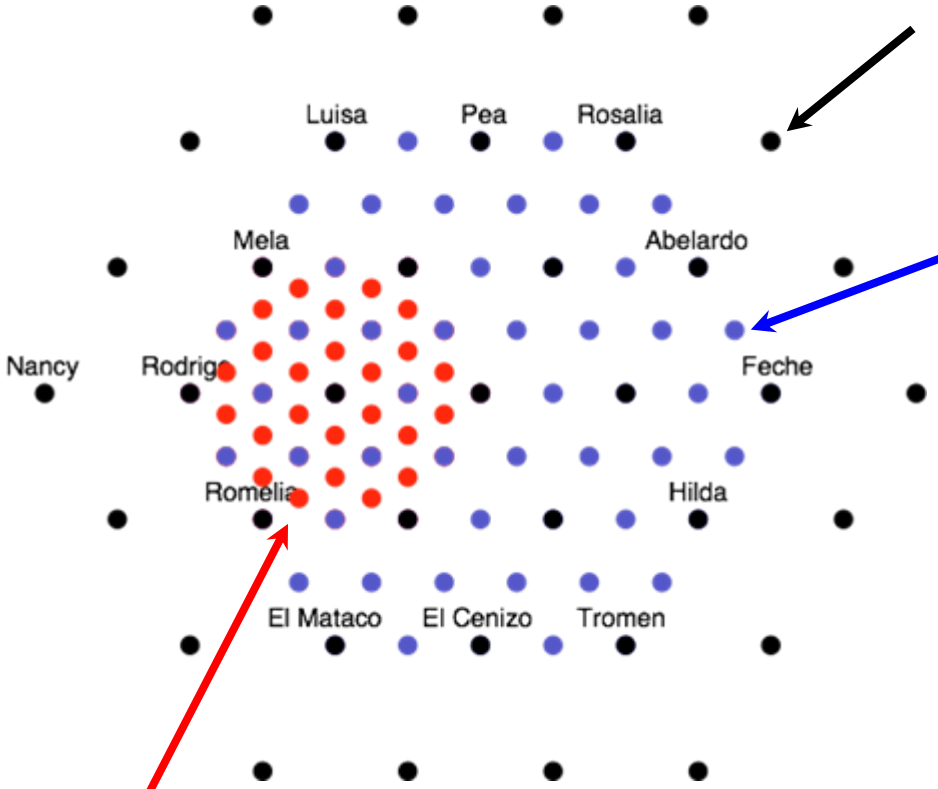
Simulated acceptance



433m 750m 1500m

Threshold for infill array ~10^{17} eV

AMIGA: Auger Muons and Infill for the Ground Array

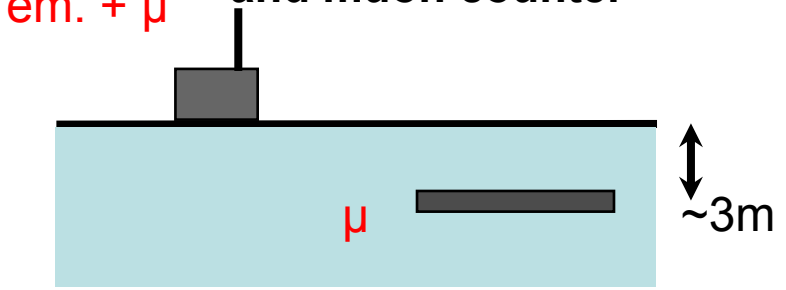


Existing tank array 1500m

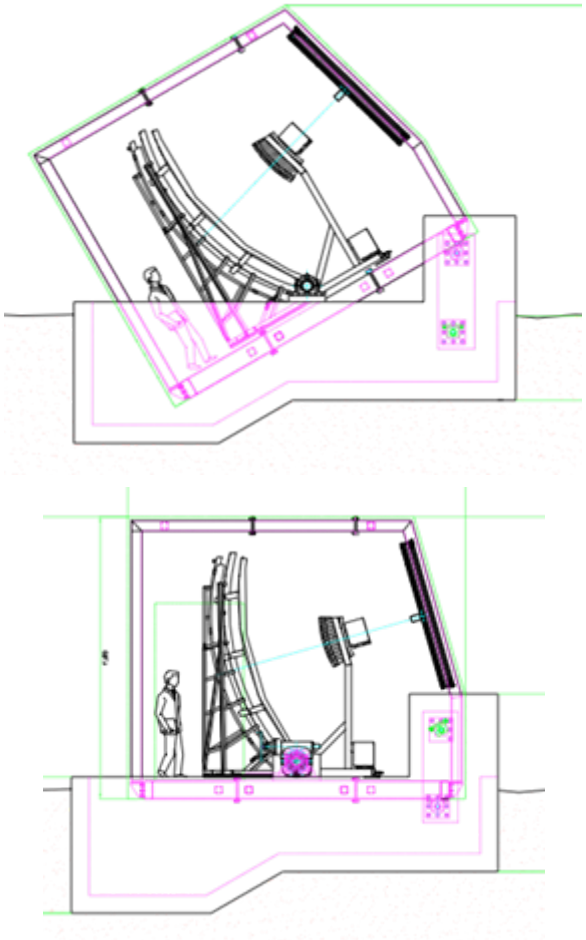
Infill array 750m
42 additional detectors
Area ~ 23.5 km²

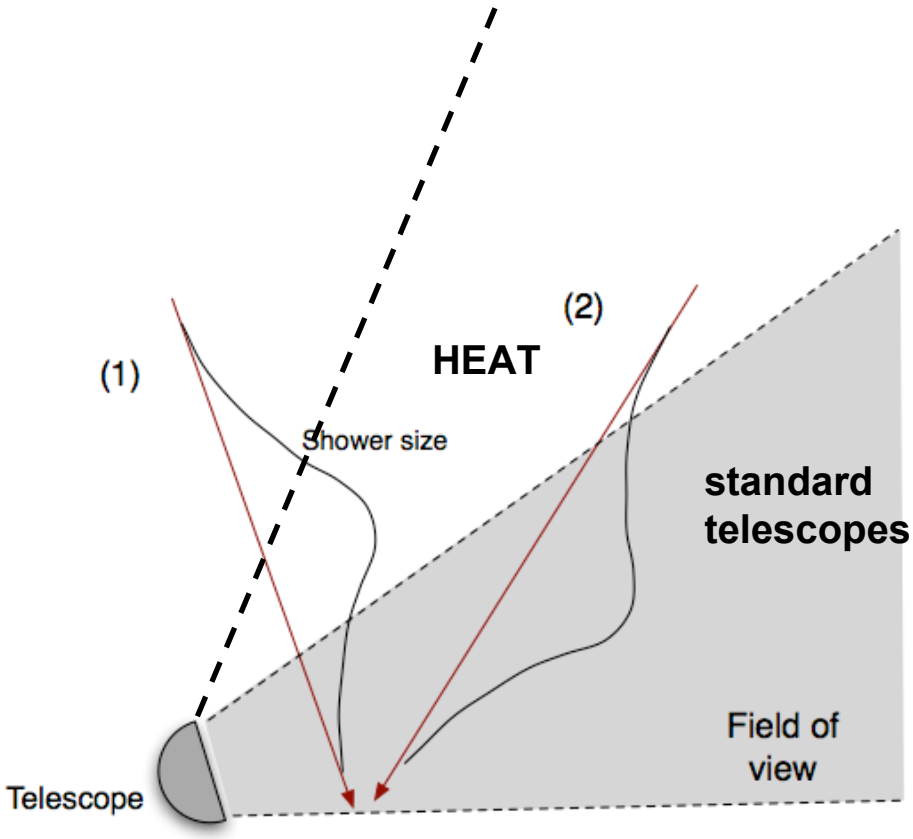
Infill array 433m
24 additional detectors
Area ~ 5.9 km²

Each of the 85 detectors:
pair of Cherenkov tank and muon counter



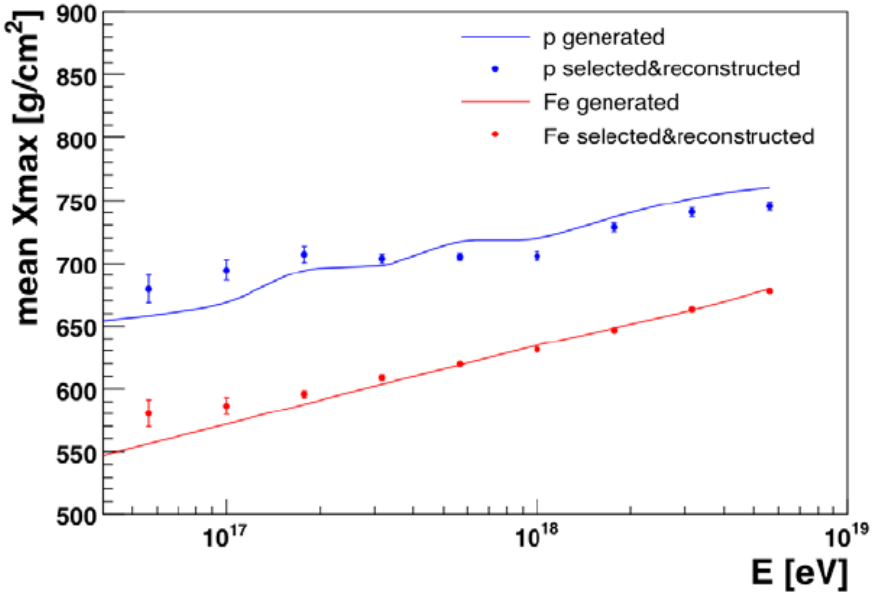
HEAT: High Elevation Auger Telescopes

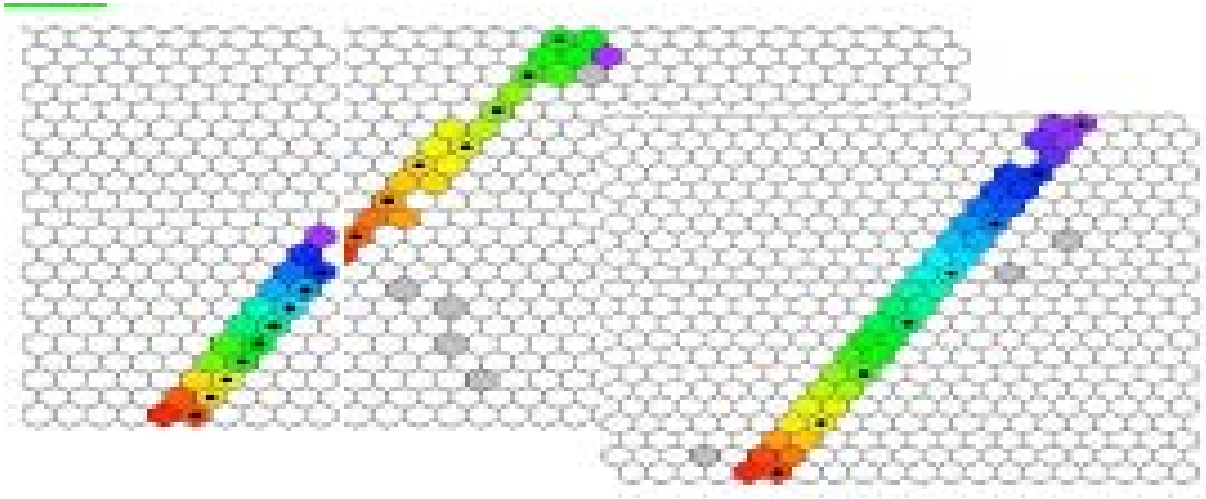




- 3 ``standard´´ Auger telescopes tilted to cover 30 - 60° elevation
- Custom-made metal enclosures
- Also prototype study for northern Auger Observatory

HEAT: High Elevation Auger Telescopes





First telescope in operation

AERA: Auger Engineering Radio Array

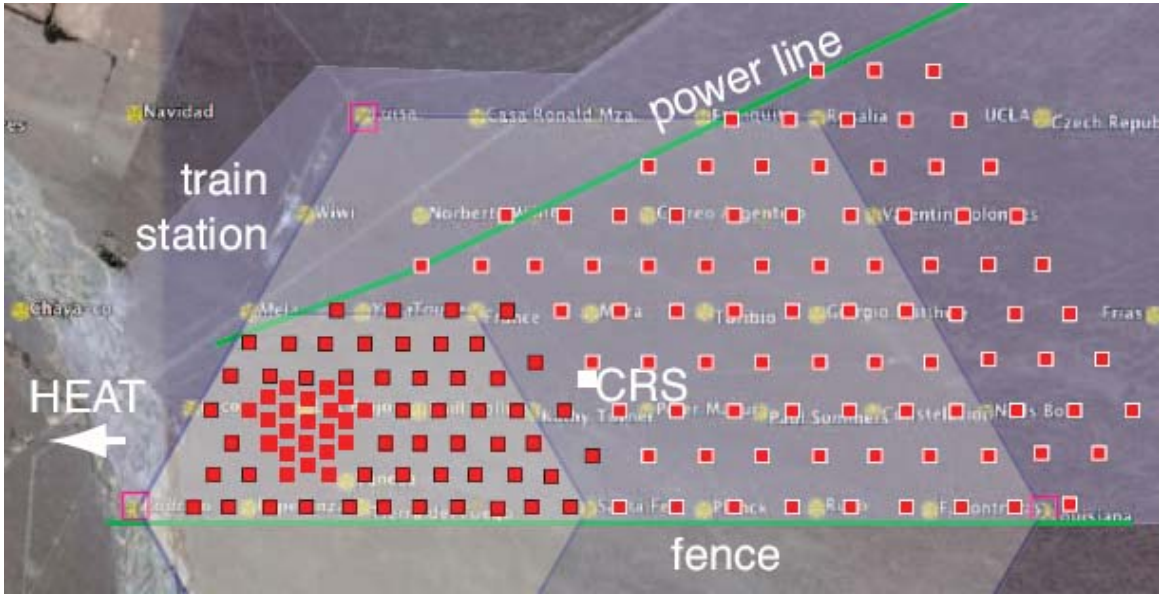
Aims:

- Establish radio detection technique
- Establish test self-trigger concepts for $E > 5 \times 10^{17}$ eV
- Calibrate radio signal
- Investigation of transition from galactic to extragalactic CR

Plan:

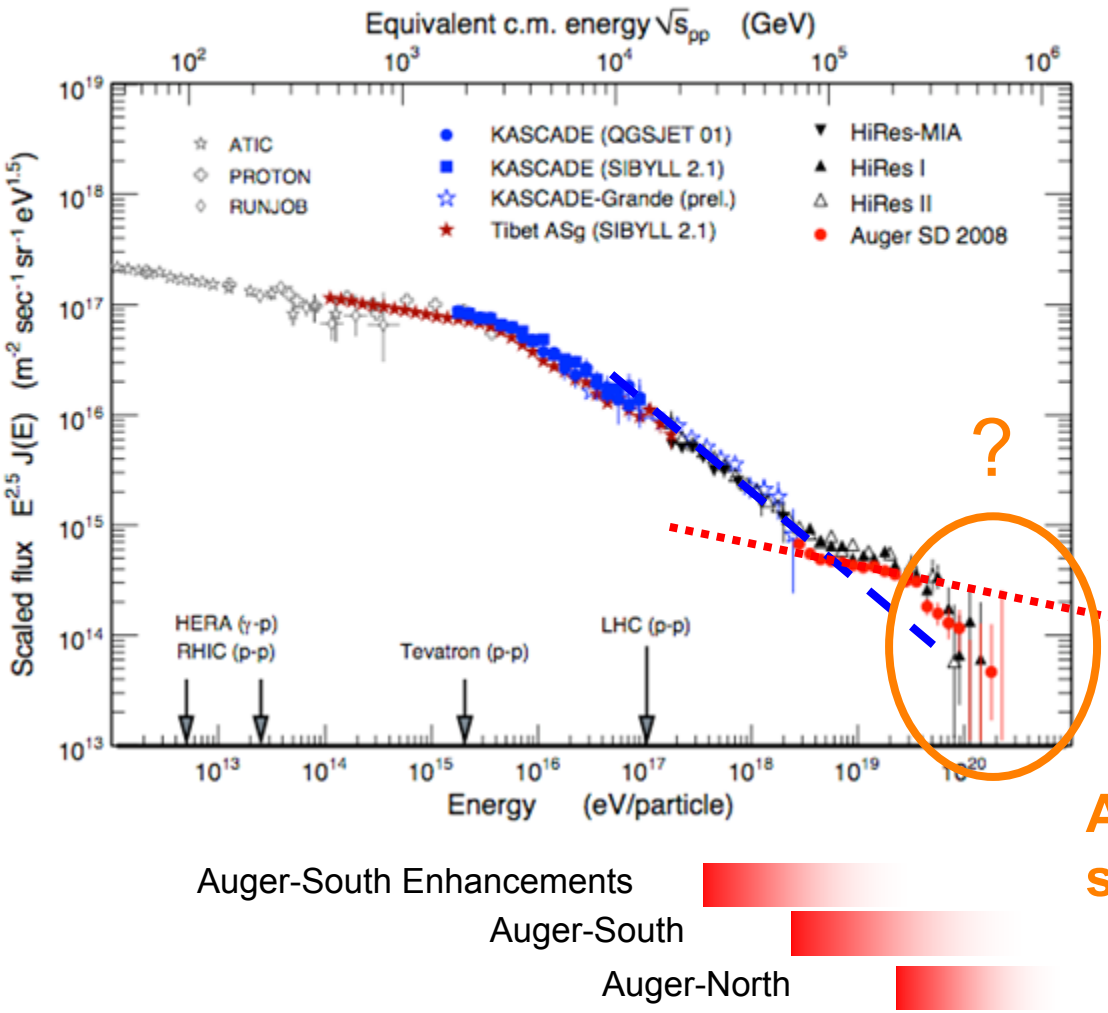
- Array of 20 km^2
- 30 - 80 MHz, 200 Ms/s
- 20 prototype antennas by end 2009
- 150 antennas by end of 2011

AERA: Auger Engineering Radio Array



First prototype of DAQ system

Go for highest energies



Auger-South Enhancements

Auger-South

Auger-North

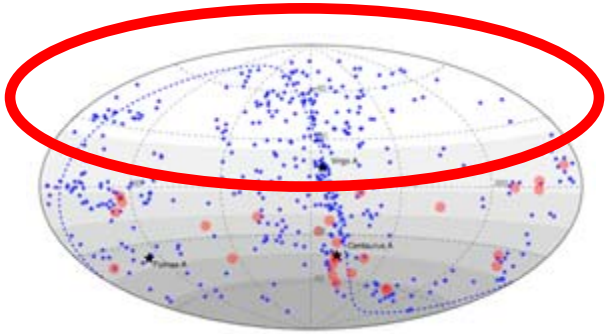
Auger-South results

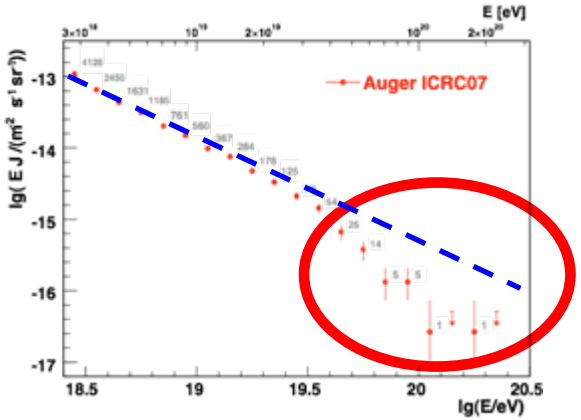
- Suppression of flux (like GZK effect)
- Anisotropy E > 6×10^{19} eV
- Mixed cosmic ray composition at lower energy
- Photon fraction small
- Neutrino flux low

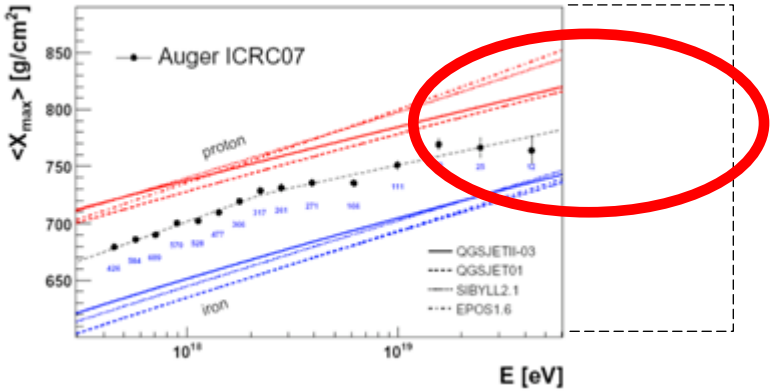
Auger-North: GZK suppression region

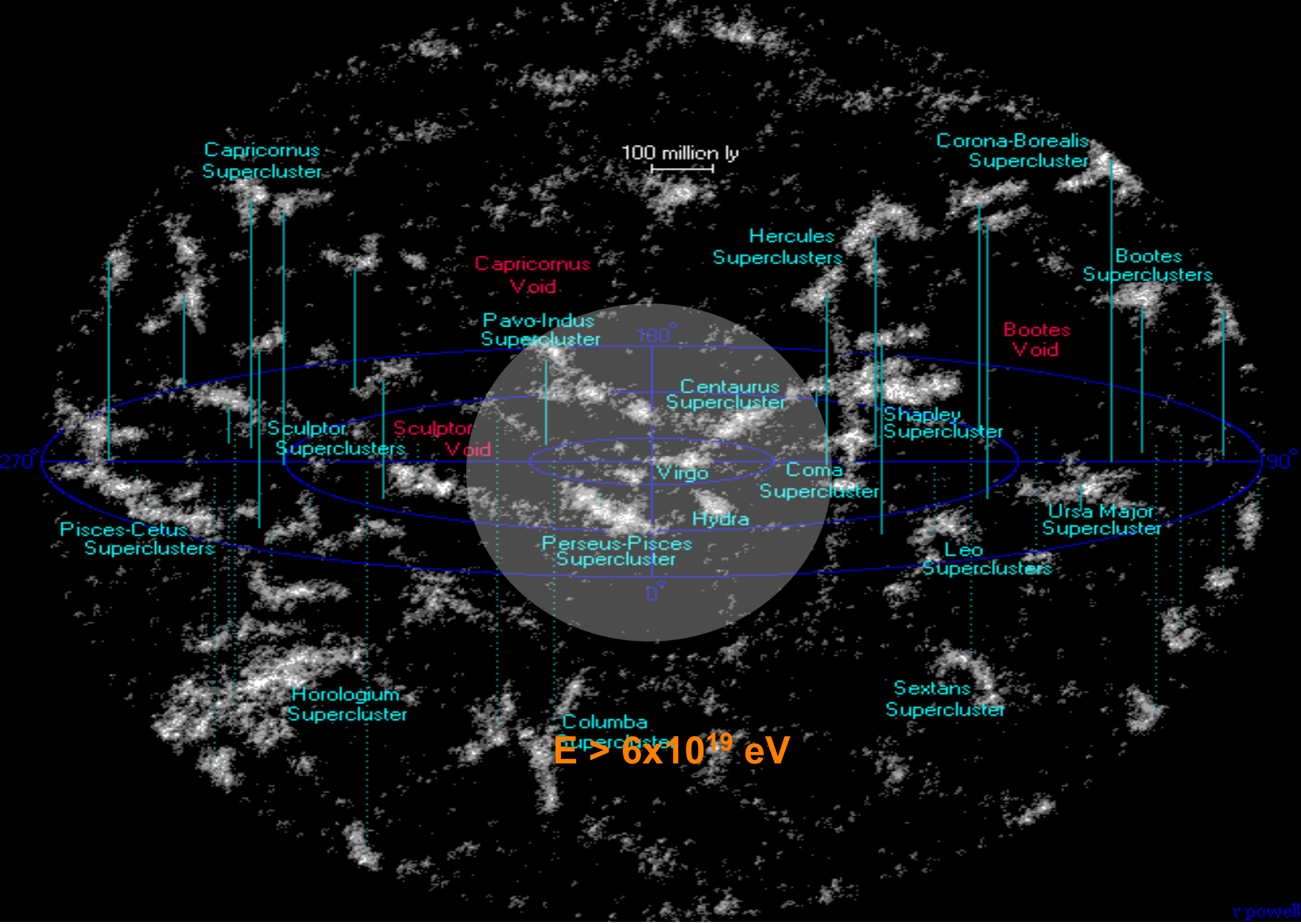
Northern Auger Observatory: Motivation and aims

- **The sources of UHECR**
  - Anisotropy ⇉ correlations ⇉ source classes
  - Study individual sources with spectra and composition on the whole sky
- **The acceleration mechanism**
  - Composition evolves from source to here
  - Proton beam !? calibration !
  - E>>10^{20} eV still difficult; E_{max} ?
- **Propagation and cosmic structure**
  - Map galactic B-field
  - Matter within 100 Mpc
  - Extragalactic B-field small ?
- **Particle physics at 350 TeV**
  - Mass and X_{max}
  - Had. interactions, cross sections ?
  - New physics, Lorentz invariance
- **Multi-messenger astrophysics**
  - Combine the data from photons, neutrinos and charged particles !
  - Sources within field of view of IceCube





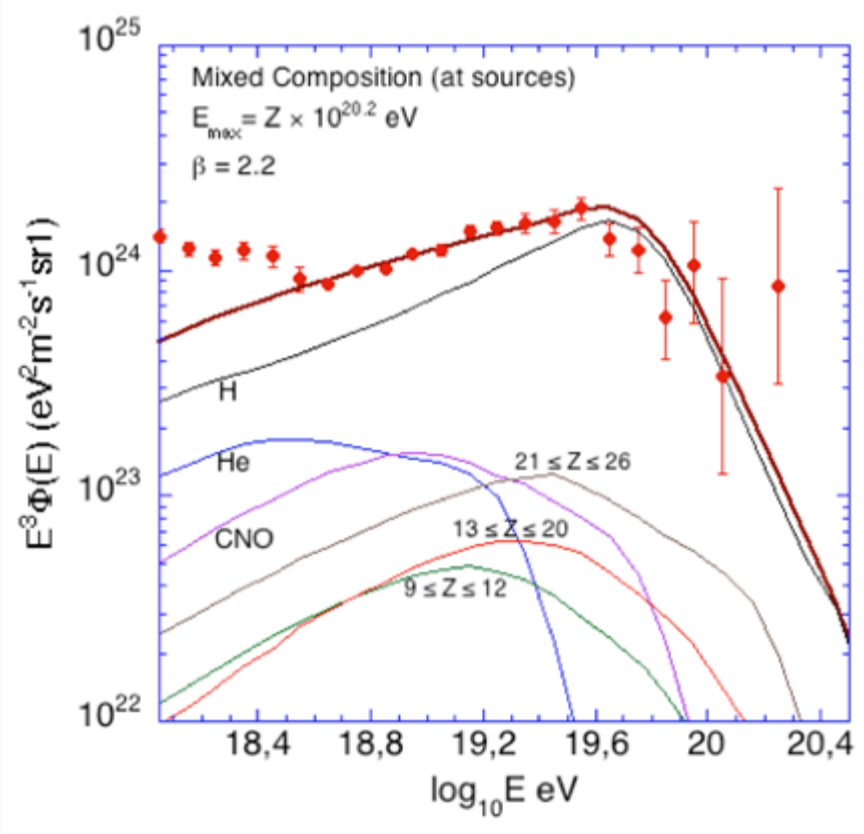


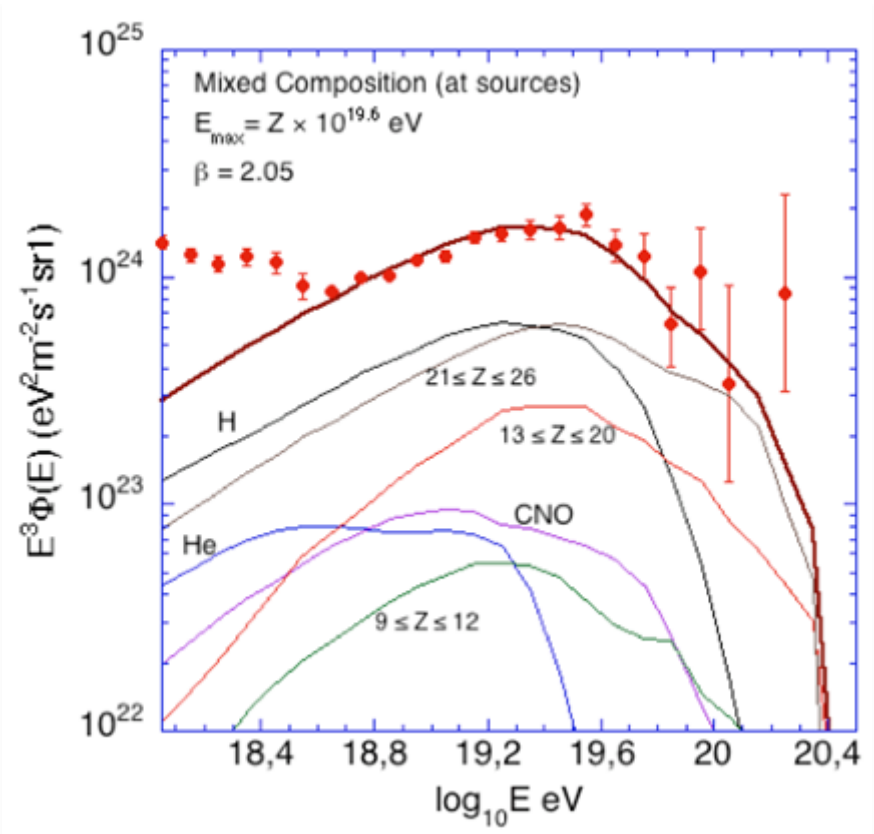

Capricornus Supercluster
100 million ly
Corona-Borealis Supercluster
Hercules Superclusters
Capricornus Void
Bootes Superclusters
Pavo-Indus Supercluster
180°
Bootes Void
Centaurus Supercluster
Shapley Supercluster
Sculptor Superclusters
Sculptor Void
270°
90°
Virgo
Coma Supercluster
Hydra
Ursa Major Supercluster
Pisces-Cetus Superclusters
Perseus-Pisces Supercluster
Leo Superclusters
0°
Horologium Supercluster
Sextans Supercluster
Columba
E > 6x10^19 eV
r powell

Particle physics with air showers

(a) Correlation with sources allow identification of particles

(b) Propagation leads to either light or heavy composition

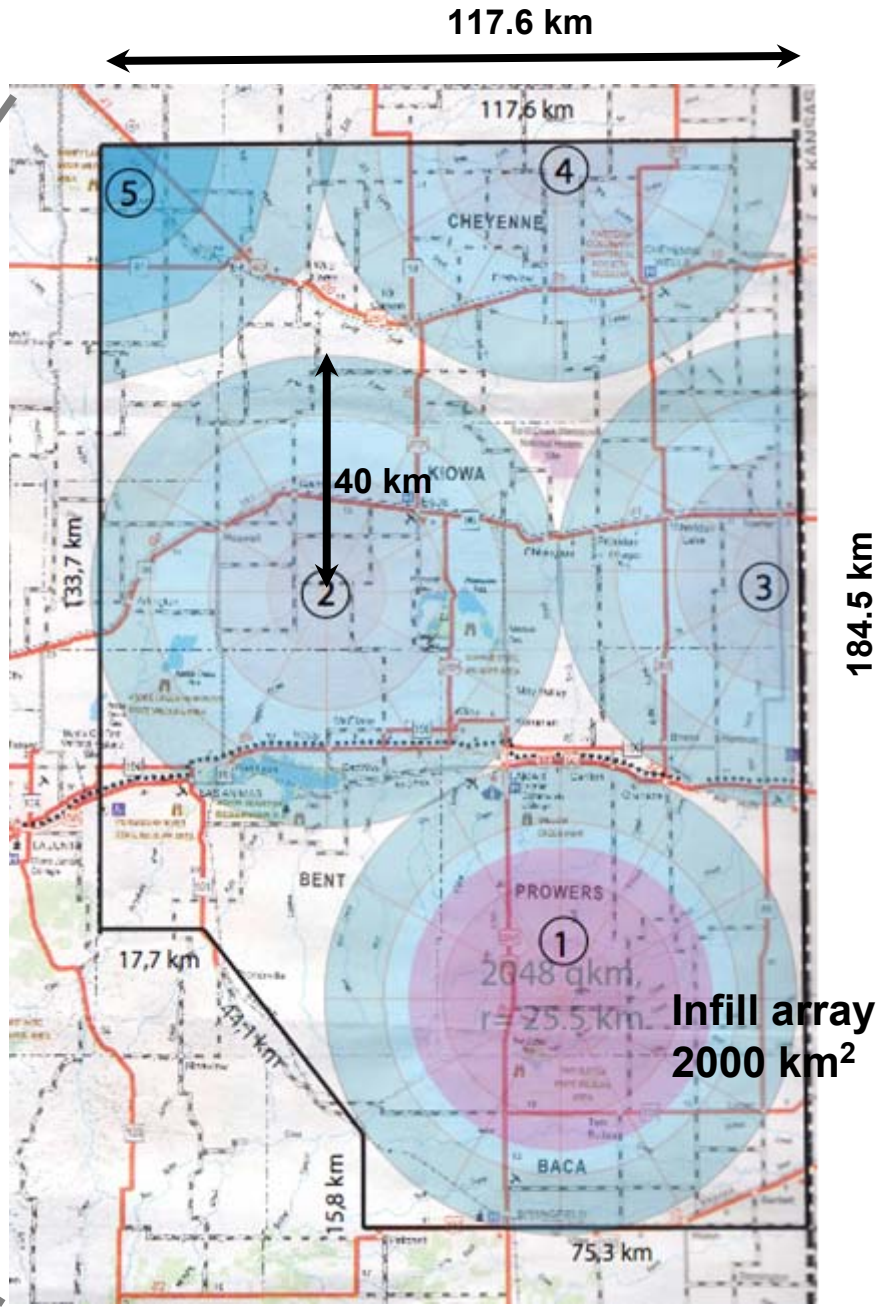




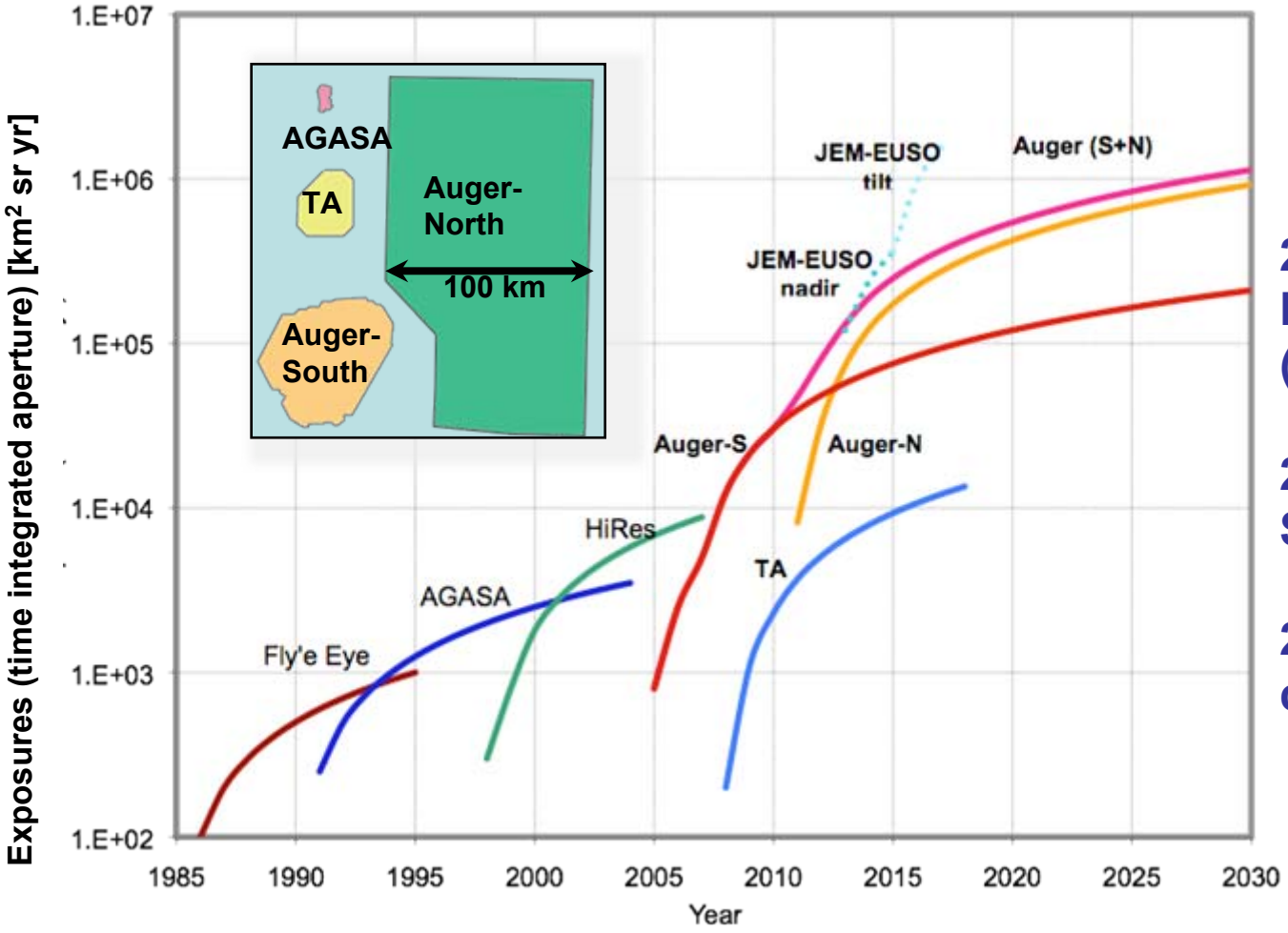
Allard et al., arXiv:0805.4779 [astro-ph]

Auger-North detector layout

- **Optimized for science and costs**
- **Surface array with 4000 stations:**
  20,000 km² with √2-mile = 2.3 km grid
- **Infill array with 400 stations:**
  2,000 km² with 1-mile = 1.6 km grid
- **39 fluorescence telescopes**



Current status and timeline



2009:
R&D array, funded
(10 detector stations)

2009-2011:
Science reviews

2012: Begin of construction (5 years)

Auger-South: $55M

Auger-North: $120M

special thanks to Ralph Engel, Matthias Kleifges