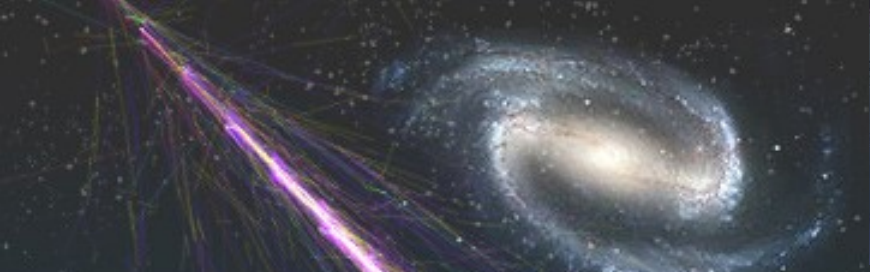


XXVIII PHYSICS IN COLLISION - Perugia, Italy, June, 25-28, 2008

UHE Cosmic rays from Earth-based observatories

Sergio Petrera, L'Aquila University

email: sergio.petrera@aquila.infn.it




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UHE Cosmic rays from Earth-based observatories

Sergio Petrera, L'Aquila University

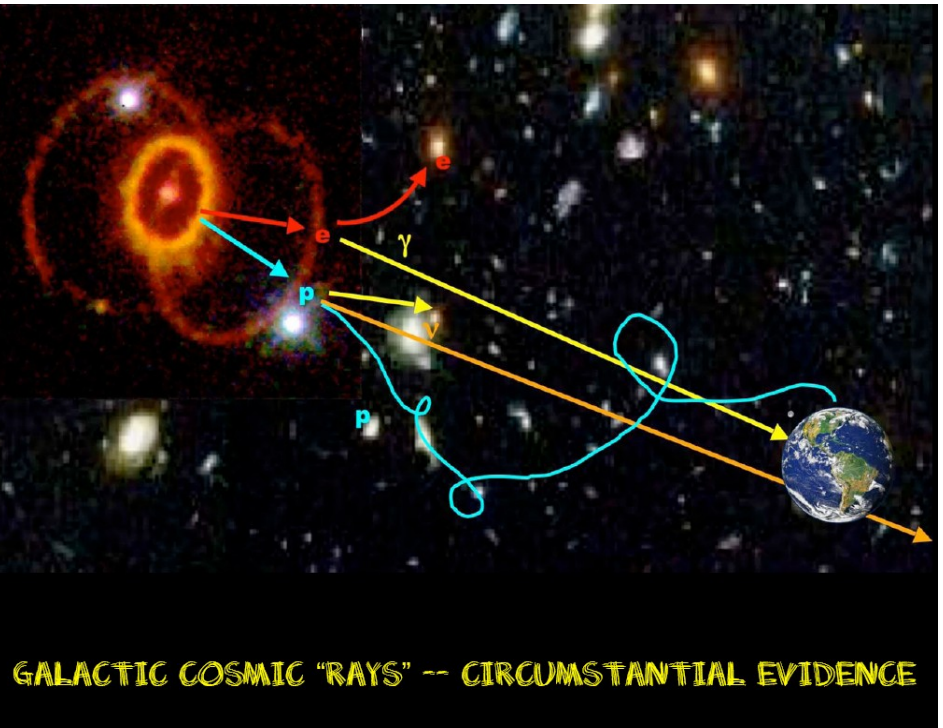
email: sergio.petrera@aquila.infn.it

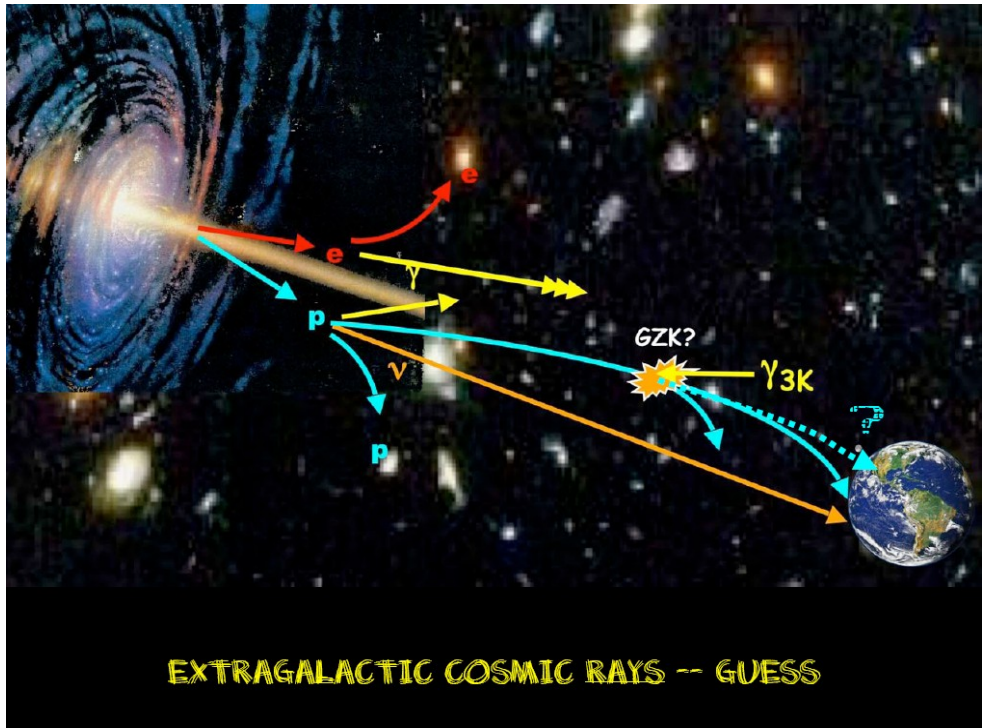
- Motivations
- Present status of the experiments
- The physics items:
  - *energy spectrum*
  - *CR composition*
  - *arrival directions*
- Summary and outlook

The interest for UHECRs in three points

$E > 10^{18}$ eV

- transition galactic/extragalactic origin
- GZK effect
- pointing to the sources (particle astronomy !?)





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The interest for UHECRs in three points

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- transition galactic/extragalactic origin
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GZK cut-off

The Greisen -Zatsepin-Kuzmin "cutoff"

At UHE, protons interact with CMB photons by photo production, and nuclei with CMB and IR photons through photo dissociation

UHECR should lose energy quickly on short distances (<100 Mpc)

$$p + \gamma \rightarrow p + \pi^{\circ}$$

$$p + \gamma \rightarrow n + \pi^{+}$$

Photoproduction Threshold

$$s = m_p^2 + 2\,E_p\,\epsilon\,(1 - \beta\cos\theta_{\gamma p}) > (m_p + m_\pi)^2$$

$$E \geq \frac{(m_p + m_\pi)^2 - m_p^2}{2\,\varepsilon\,(1 - \cos\theta_{\gamma e})} \geq \frac{(m_p + m_\pi)^2 - m_p^2}{4\,\varepsilon}$$

$$E > 6 \times 10^{19} \left(\frac{10^{-3}\ \mathrm{eV}}{\varepsilon}\right)\ \mathrm{eV}$$

The interest for UHECRs in three points

$E > 10^{18}$ eV

- transition galactic/extragalactic origin
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The interest for UHECRs in three points

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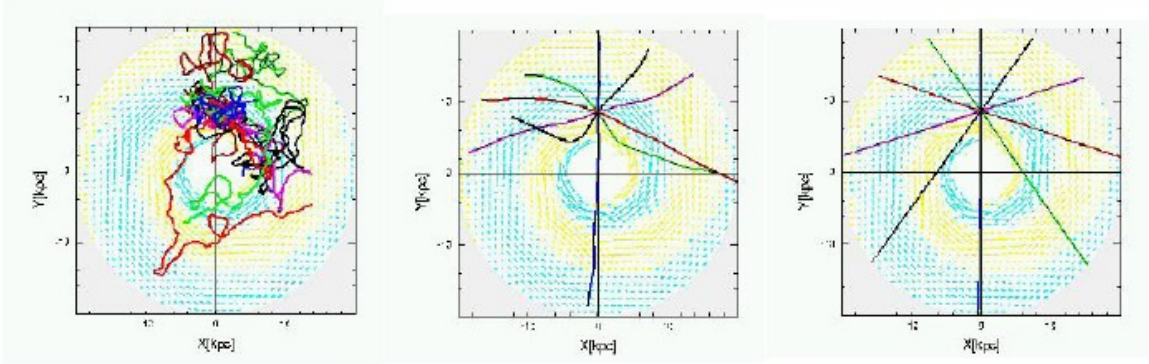
UHECR Astronomy

Magnetic fields

At low energies, CR are deflected by galactic and extra-galactic magnetic fields.
UHECR should point to the source



10^{18} eV | 10^{19} eV | 10^{20} eV

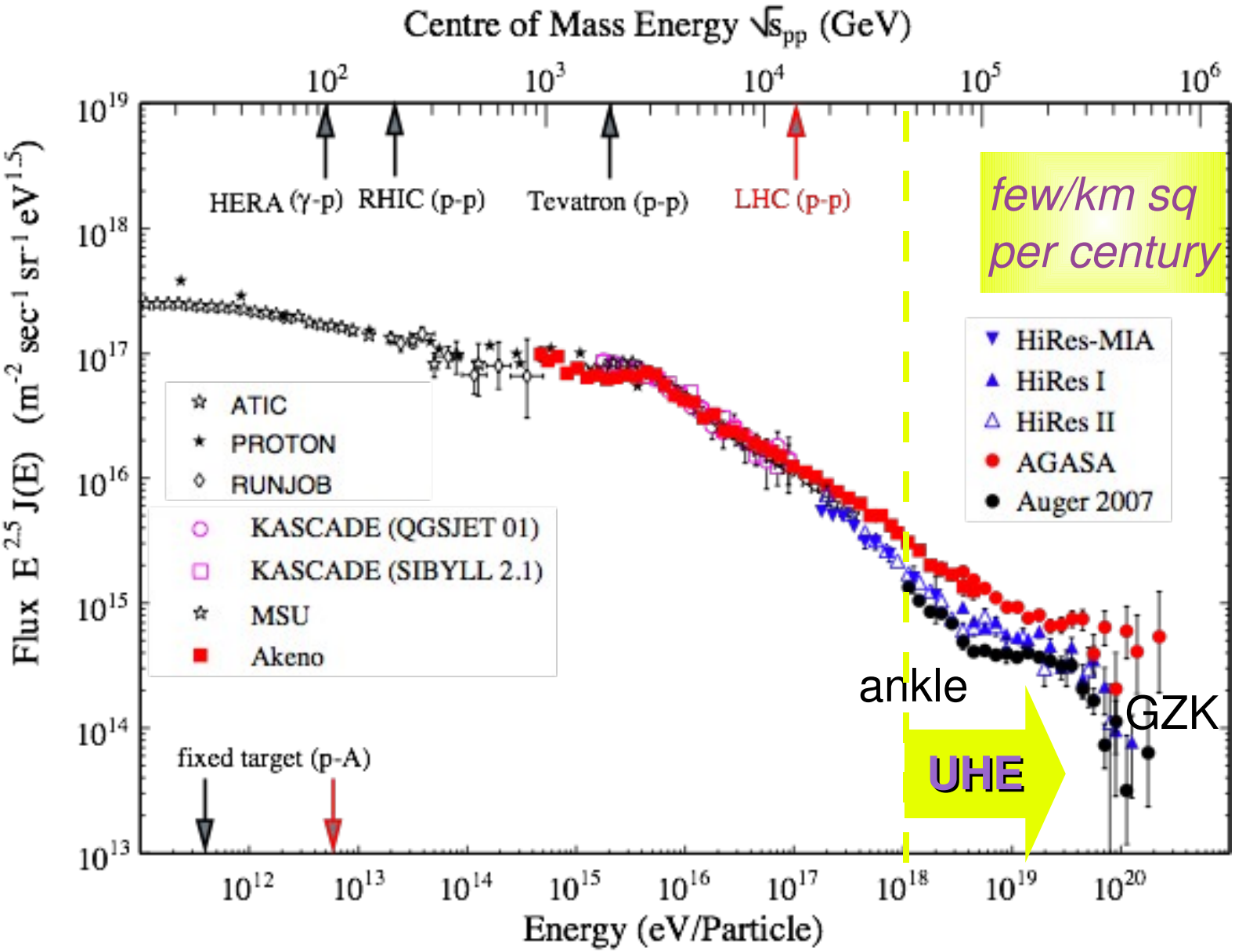
+ GZK ⇨ reduces the horizon

AGASA: surface array *stopped Jan. 2004*

HiRes: fluorescence telescopes *stopped Apr 2006*

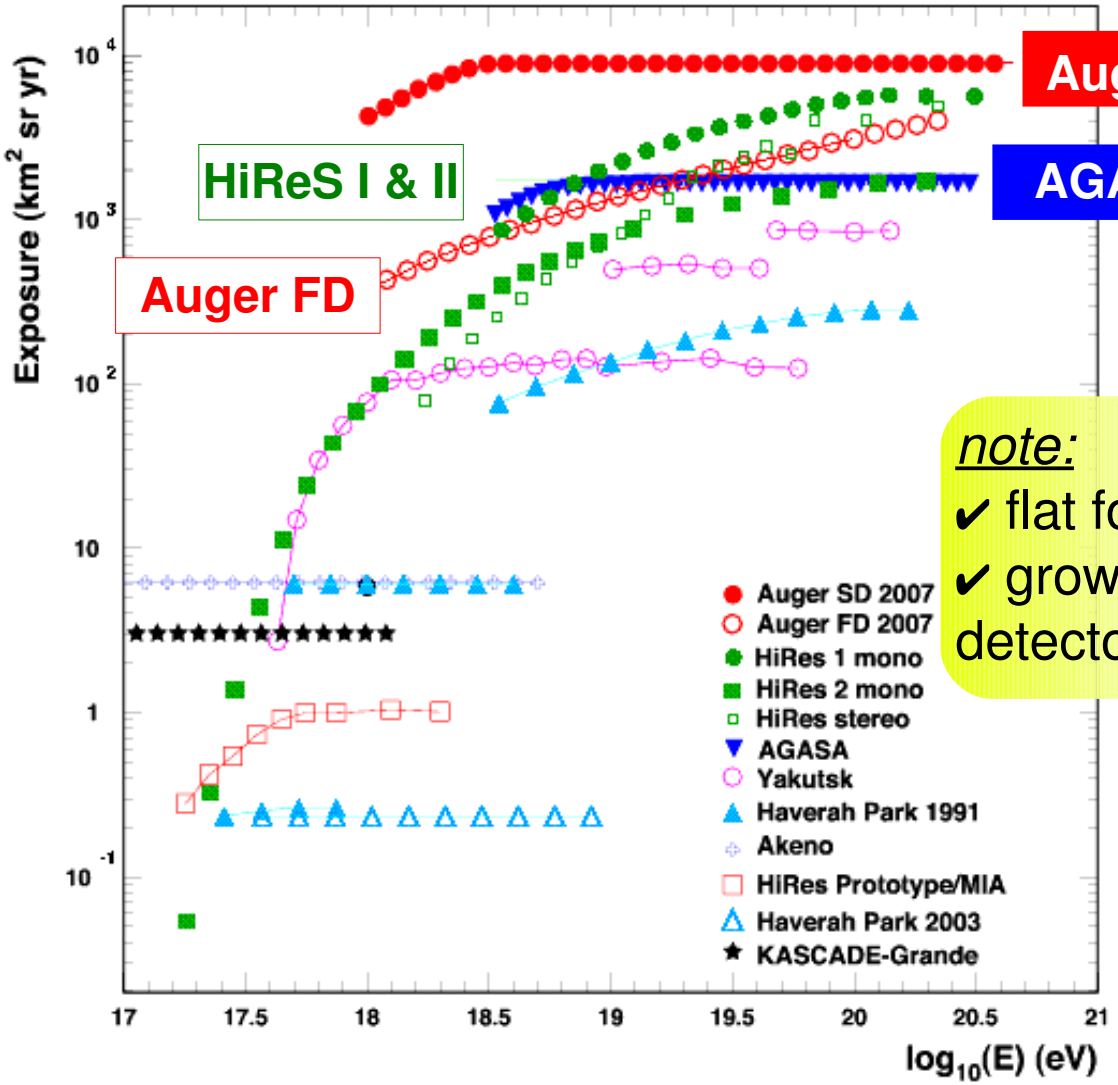
Auger: hybrid system (30xAGASA, 6xHiRes) *operating*

the all-particle spectrum



Exposures 2007

K-H. Kampert
Proceedings TAUP 2007



~7000 x yr

note:

✔ flat for surface arrays

✔ growing for fluorescence detectors

The HiRes Experiment

- HiRes-I
  - 21 mirrors
  - 1 ring, full azimuth, 3°-17° elevation
  - Sample & Hold DAQ System
  - Took data: June 1997-April 2006

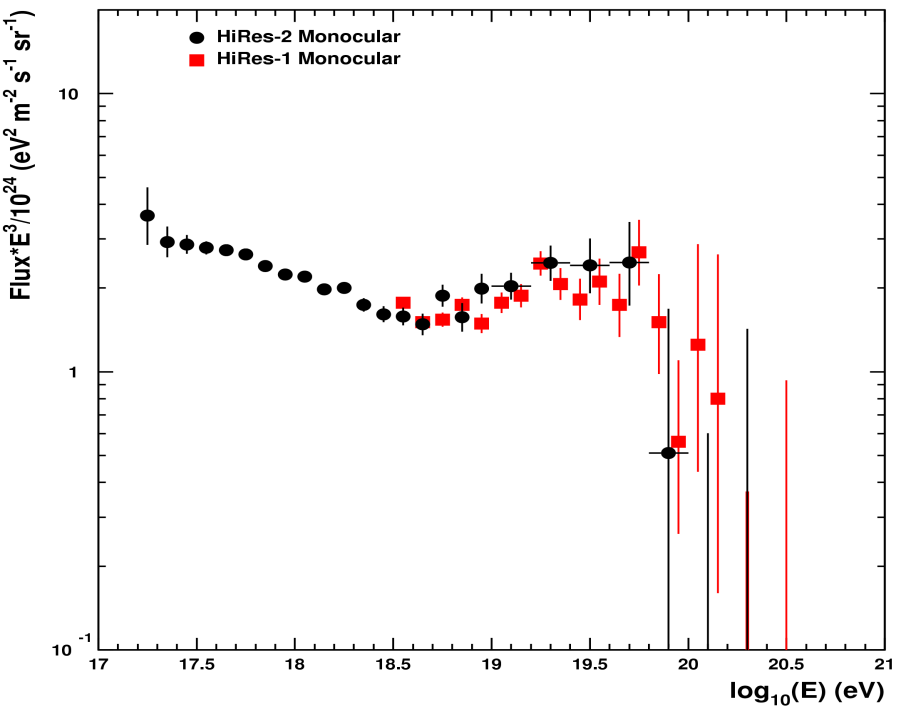
- HiRes-II
  - 42 mirrors
  - 2 rings, full azimuth, 3°-31° elevation
  - FADC DAQ System
  - Took data: Dec. 1999-April 2006

Fluorescence detector

- Both:
  - 5.1 m^2 mirrors, 16x16 PMTs

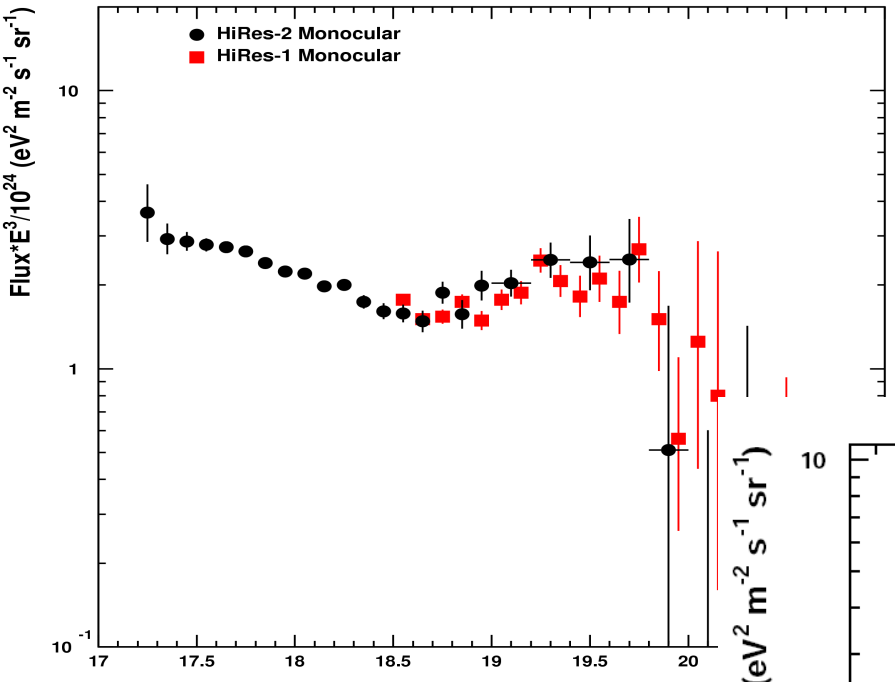
slide from D. Bergmann

HiRes monocular spectrum



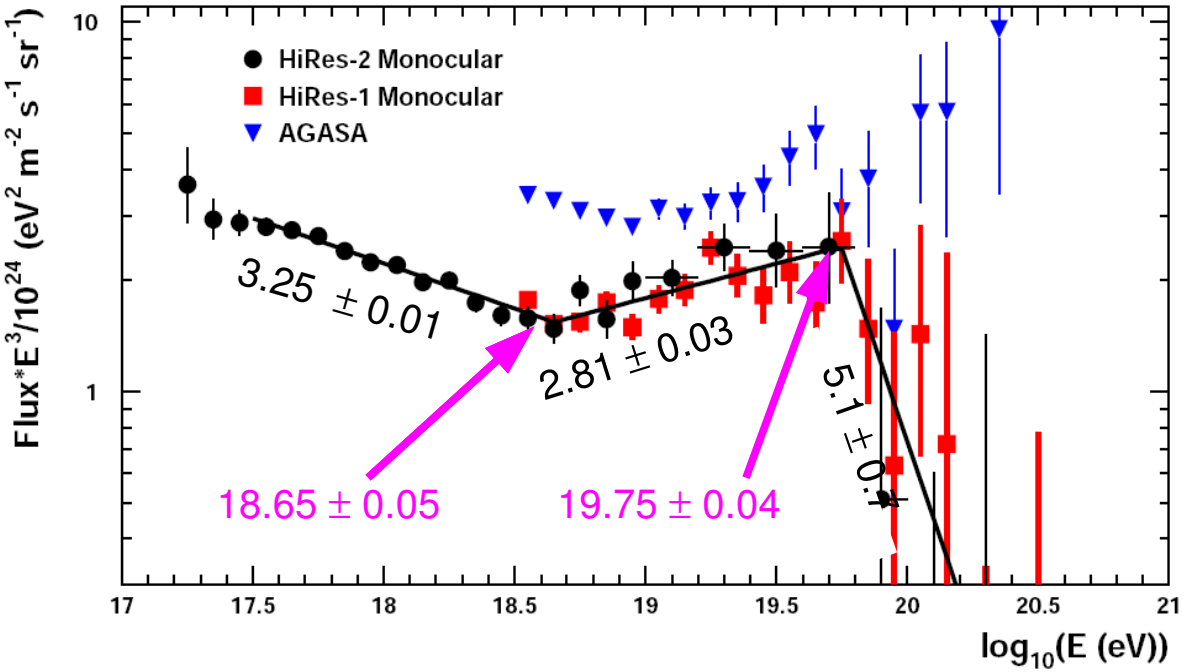
- agreement between mono data
- prominent features (ankle, GZK) clearly visible

HiRes monocular spectrum



- agreement between mono data
- prominent features (ankle, GZK) clearly visible
- ***disagreement with AGASA***

(superGZK ?? top-down scenario ?)



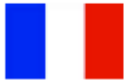
- break points and spectra indexes determined
- GZK evidence at ~ 5 σ

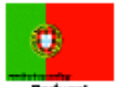
R.U. Abbasi, et al (HiRes Coll.), PRL 2008

The Pierre Auger Observatory

Colorado, USA
(in planning)

Mendoza, Argentina
(construction underway)

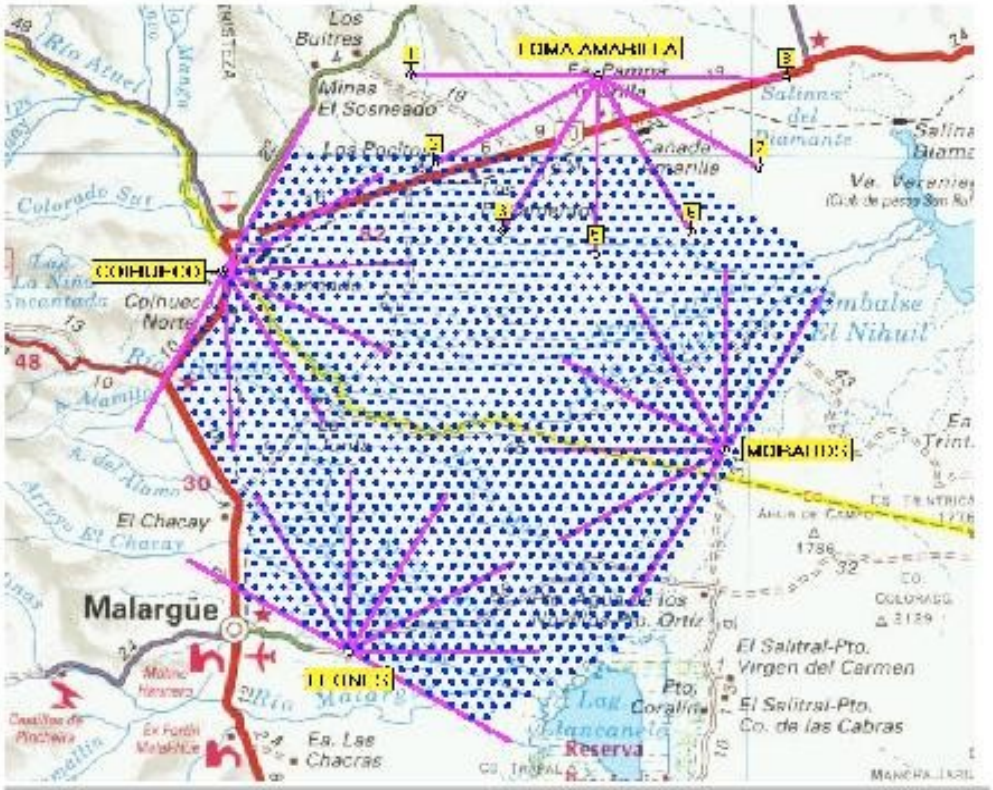




~400 scientists from 70 institutions in 17 countries

A Giant Hybrid Observatory

Auger South: the plan



Surface Array

1600 detector stations

1.5 km spacing

3000 km²

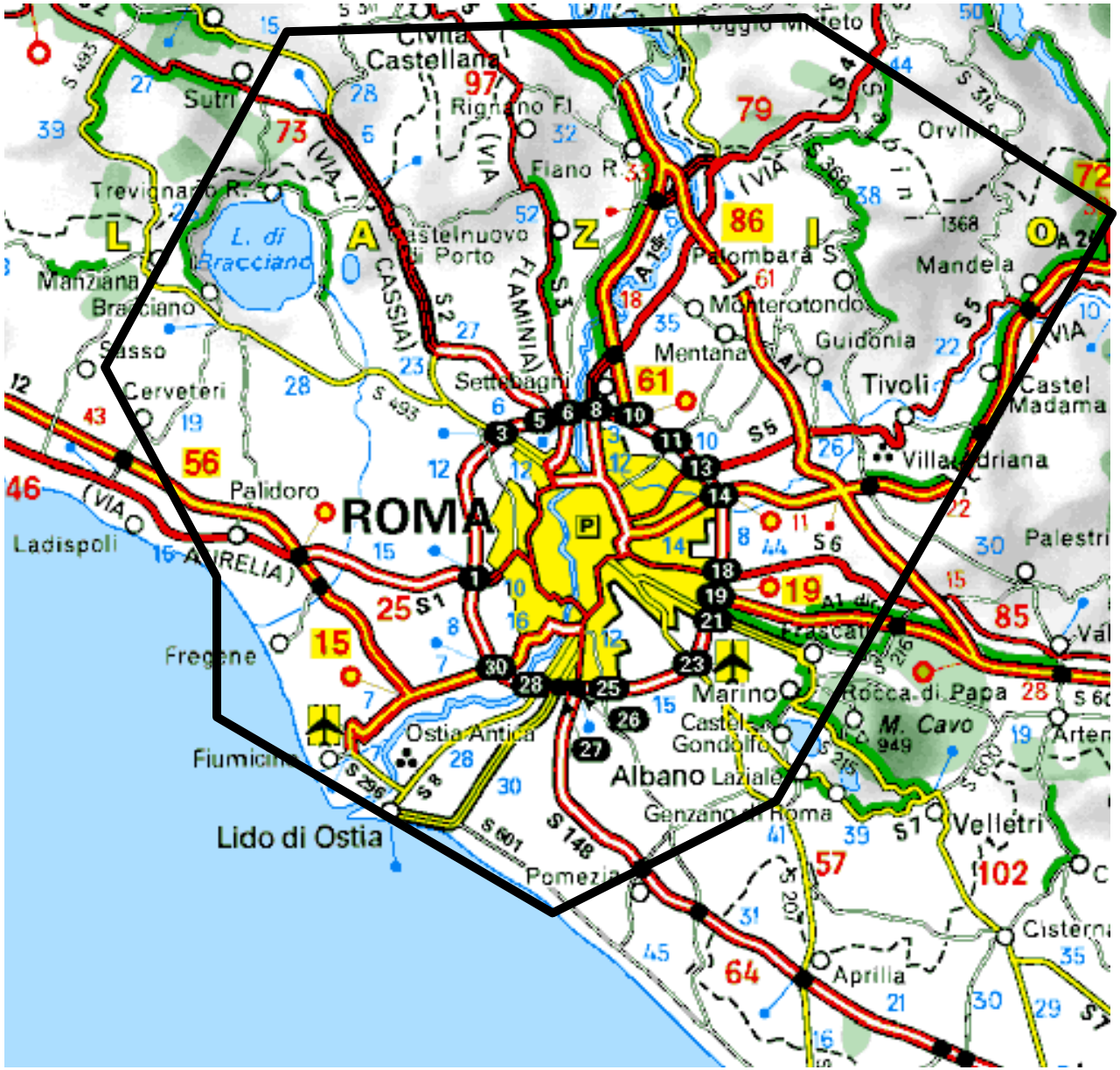
Fluorescence Detectors

4 Telescope enclosures

6 Telescopes per enclosure

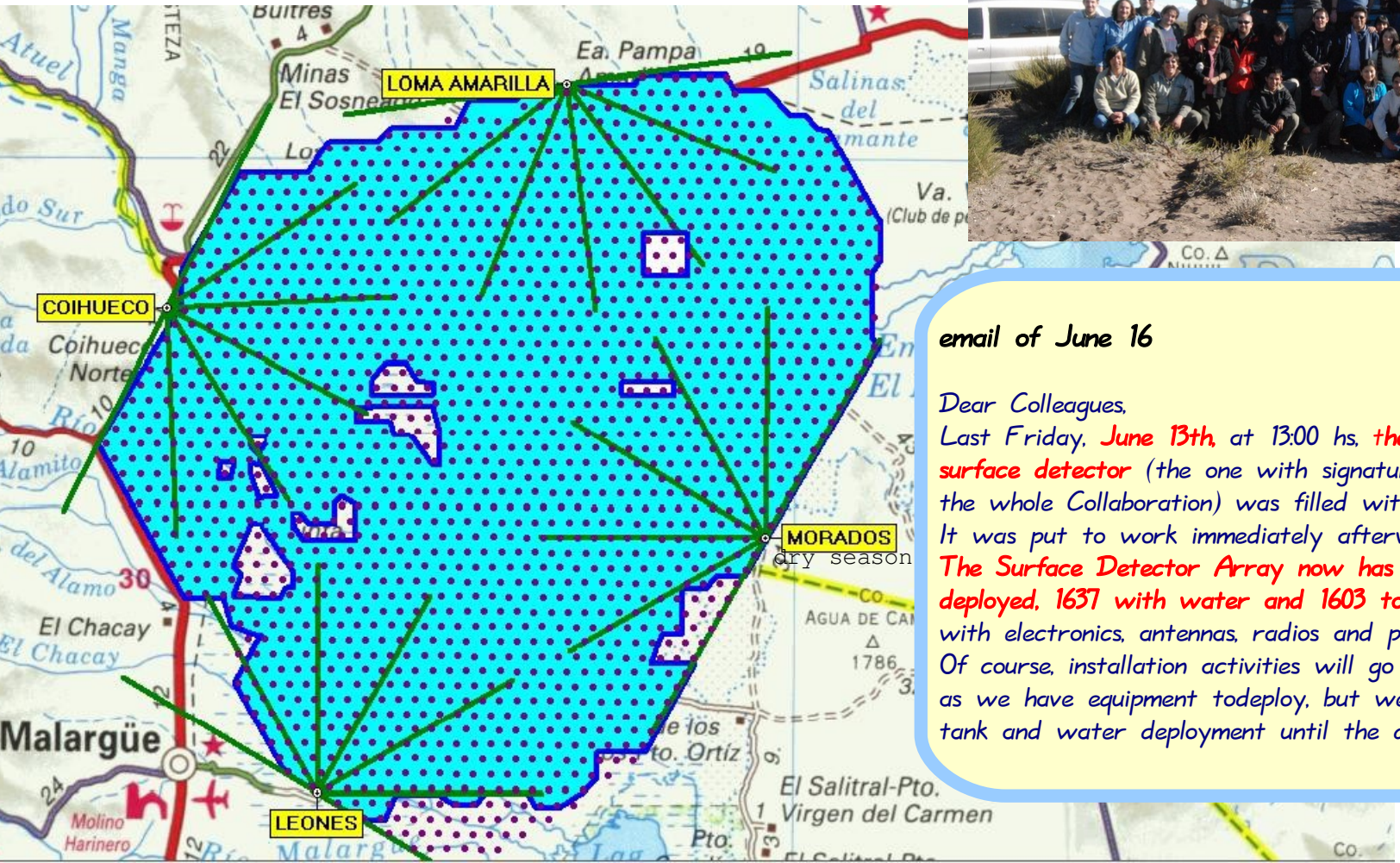
24 Telescopes total

3000 km^2 area



The Observatory Status

Now



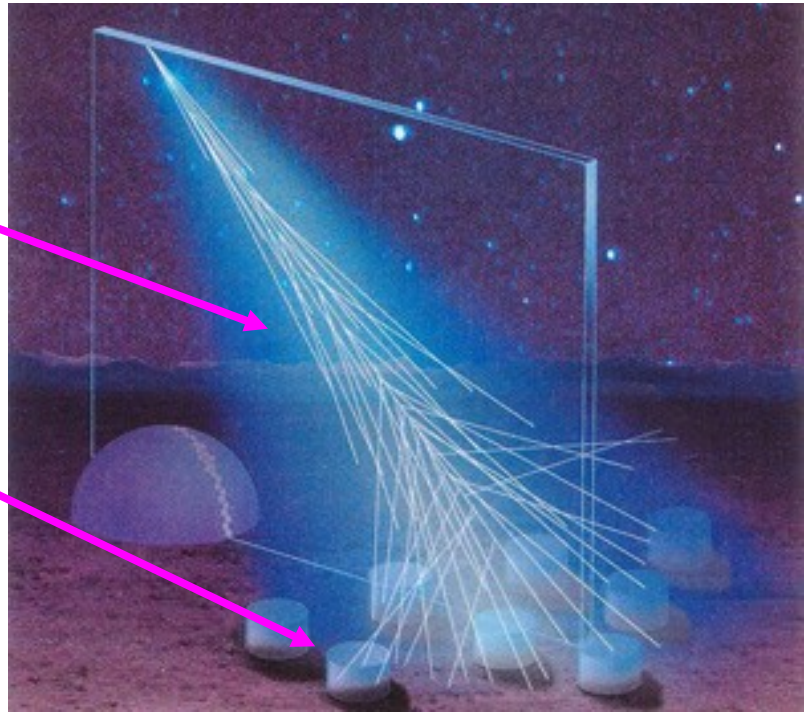
email of June 16

Dear Colleagues,
Last Friday, **June 13th**, at 13:00 hs, **the "last" surface detector** (the one with signatures from the whole Collaboration) was filled with water. It was put to work immediately afterwards.
The Surface Detector Array now has 1660 tanks deployed, 1637 with water and 1603 totally equipped with electronics, antennas, radios and power.
Of course, installation activities will go on as long as we have equipment todeploy, but we will be stopping tank and water deployment until the dry season.

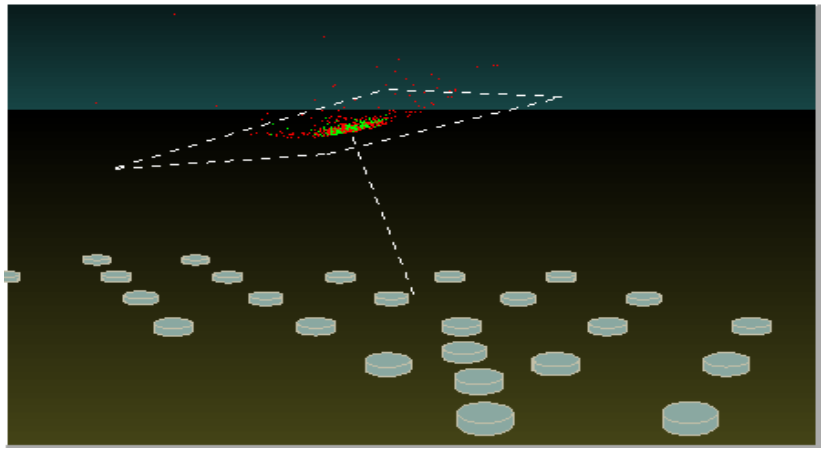
Auger detection techniques

Nitrogen fluorescence detected as shower develops

Particles detected as they reach ground



- Fluorescence (50 W light bulb @ c)
  - nearly calorimetric
  - direct view of shower evolution
  - 10% duty cycle
  - Acceptance depends on energy + atmosphere
- Surface (10^{12} particles over 20 km^2)
  - 100% duty cycle
  - Flat acceptance above threshold
  - Indirect measurements of primary energy and mass (relies on simulation)



Hybrid = surface + fluorescence

the Surface Detector

Water Cherenkov tank

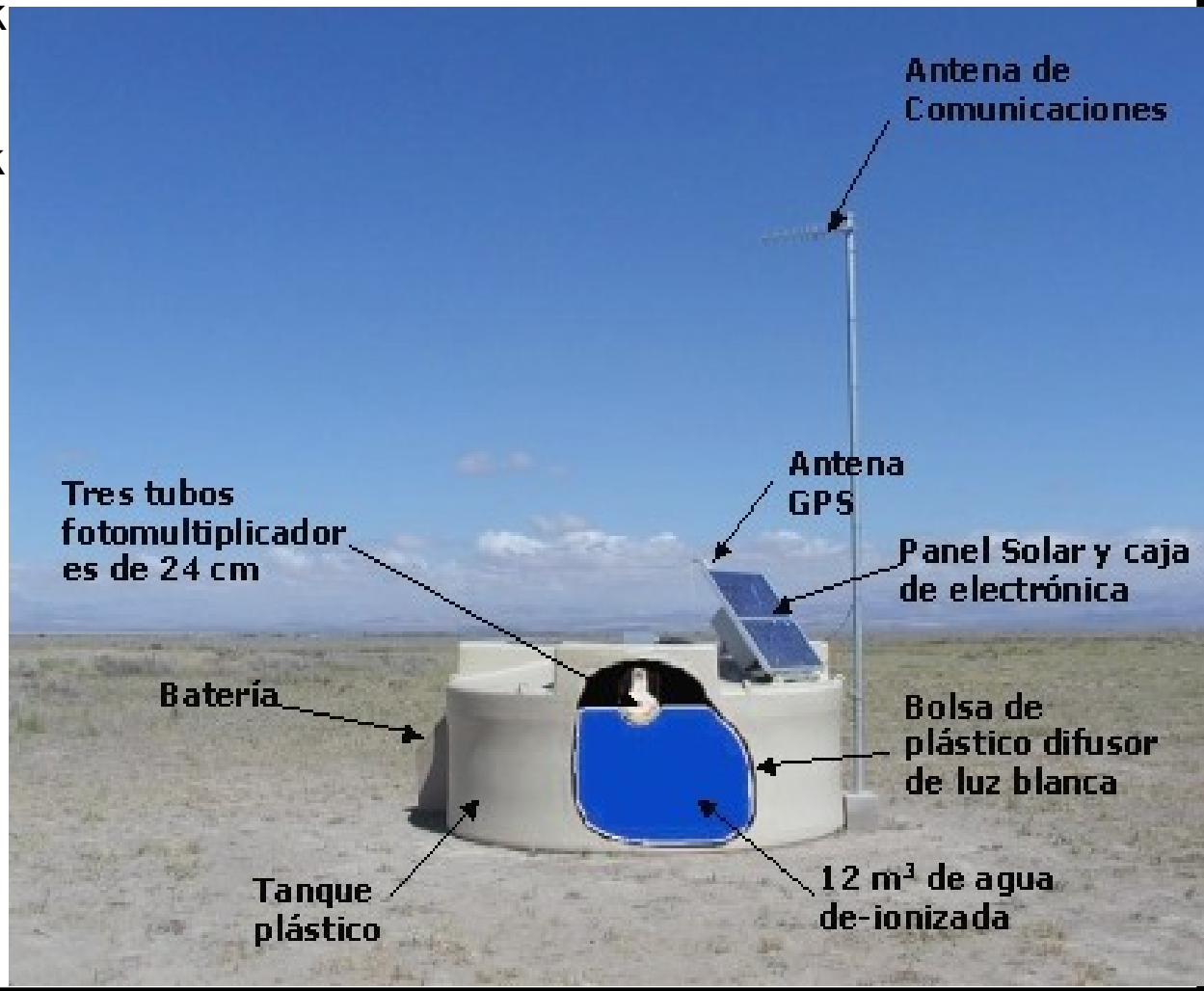
Rotomolded polyethylene tank

10 m^2 x 1.2 m of ultrapure water in a light diffusing Tyvek liner,

3 PMTs Photonis (9'' diameter);

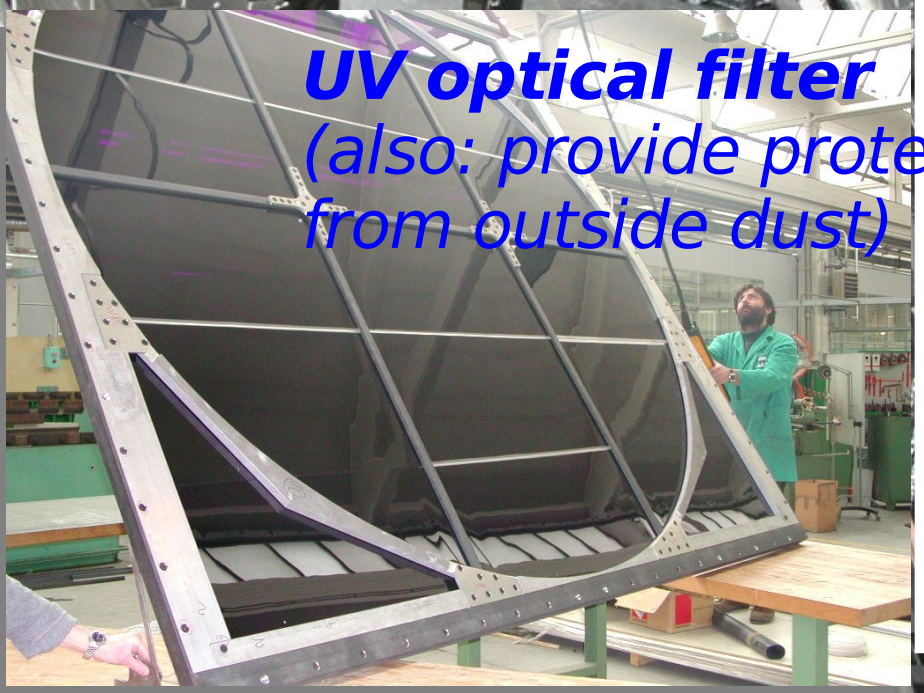
Autonomous unit: solar panel+battery, GPS timing, communication antenna, electronics

Max 10 W power consumption

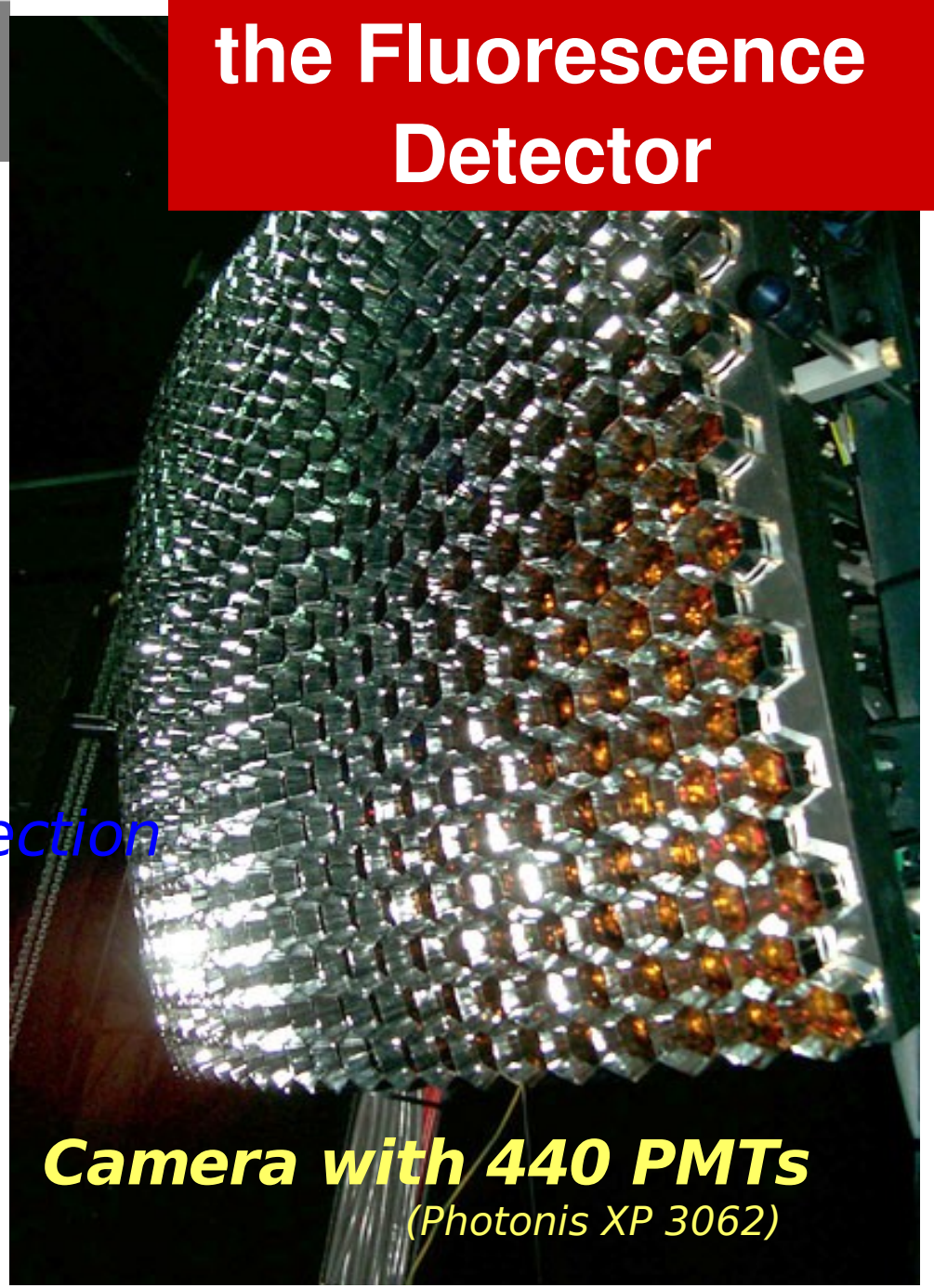


the Fluorescence Detector

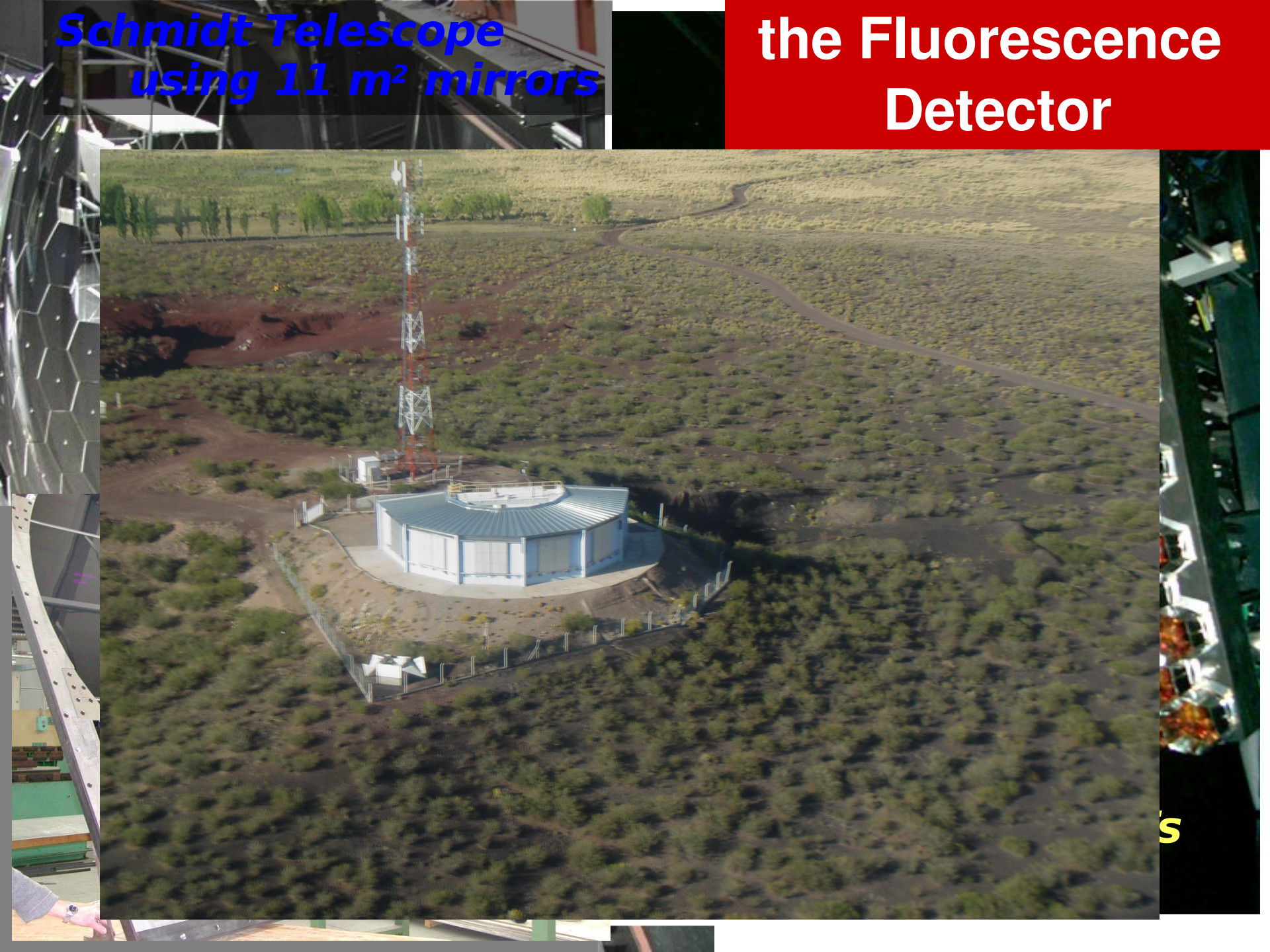
Schmidt Telescope using 11 m² mirrors

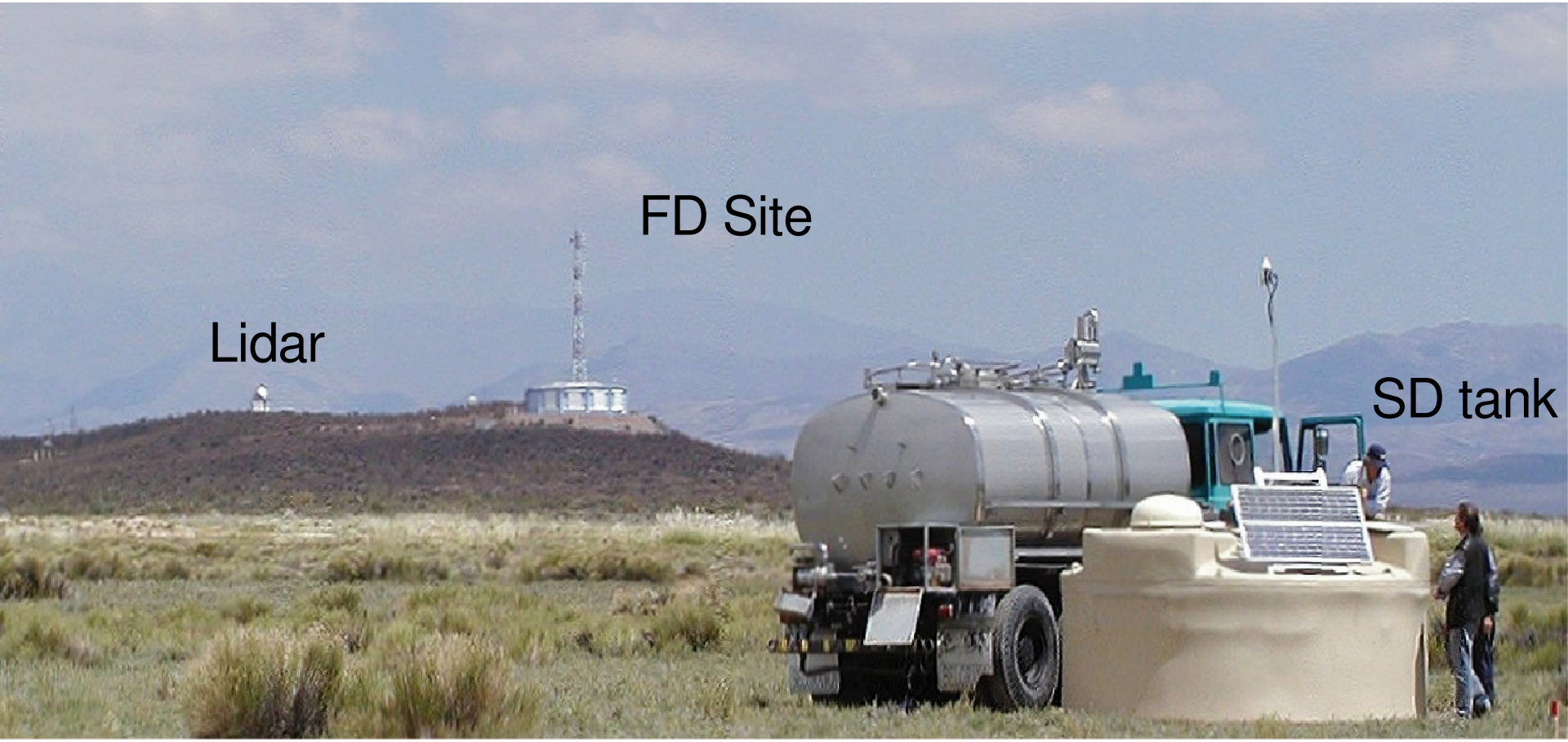


UV optical filter
(also: provide protection from outside dust)



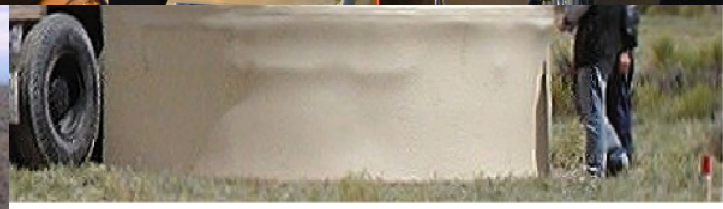
Camera with 440 PMTs
(Photonis XP 3062)


Schmidt Telescope
using 11 m² mirrors
the Fluorescence
Detector


FD Site
Lidar
SD tank

F

Men at work



Lidar

F

Men at work

Men in trouble...

Event 3637800

public online event display 1% of data! http://www.auger.org

See CR incoming direction | See individual station data

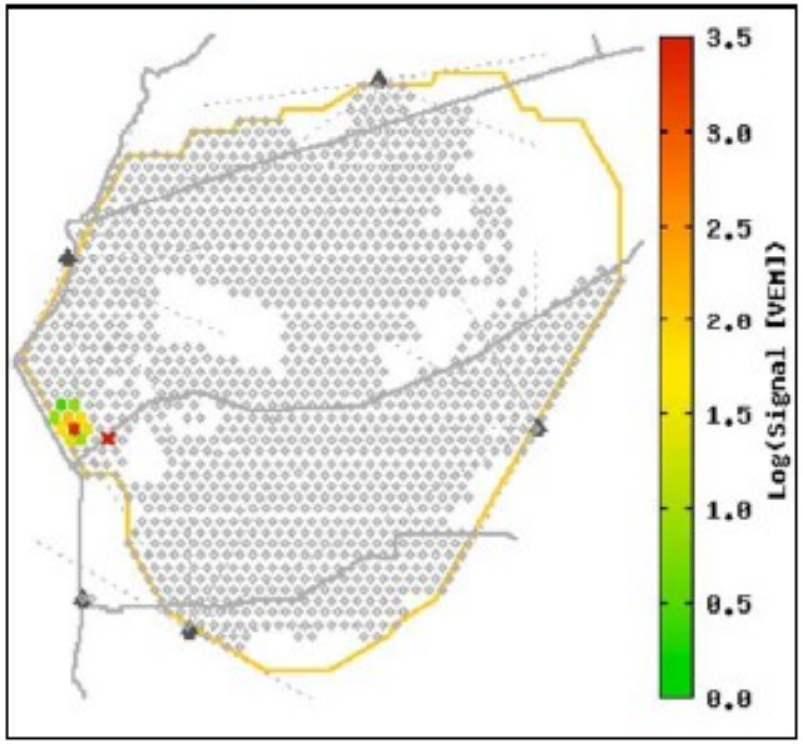


Figure 1: Southern array global view

Generic Information	
Id	3637800
Date	Sun Jul 1 15:42:38 2007
Nb Station	10
Energy	30.4 ± 1.5 EeV
Theta	24.6 ± 0.2 deg
Phi	11.0 ± 0.5 deg
Curvature	8.7 ± 0.4 km
Core Easting	445893 ± 27 m
Core Northing	6094828 ± 21 m
Reduced Chi^2	6.17

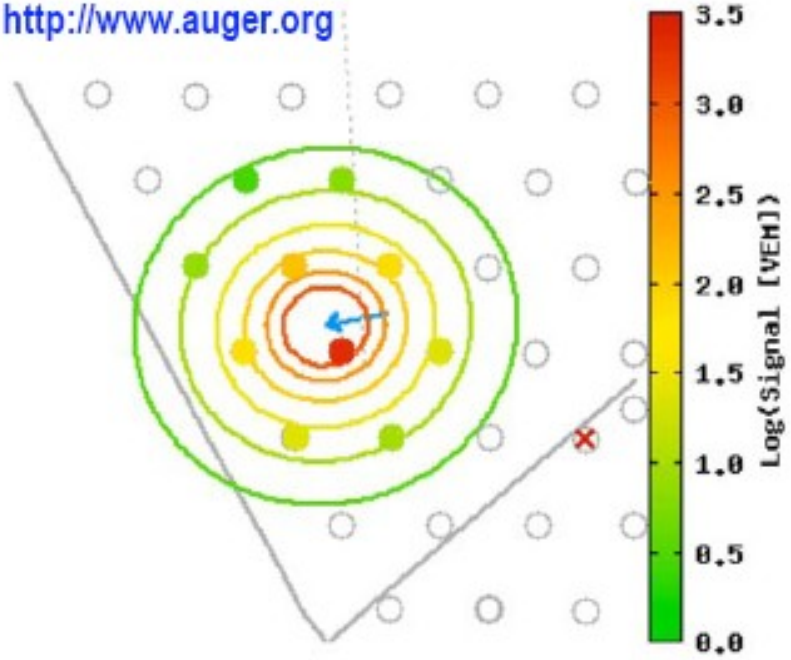


Figure 2: Southern array zoomed view

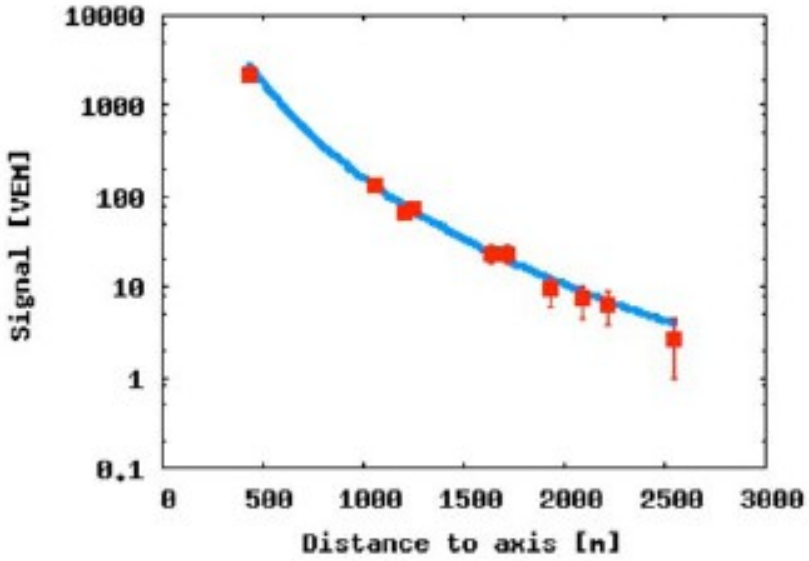
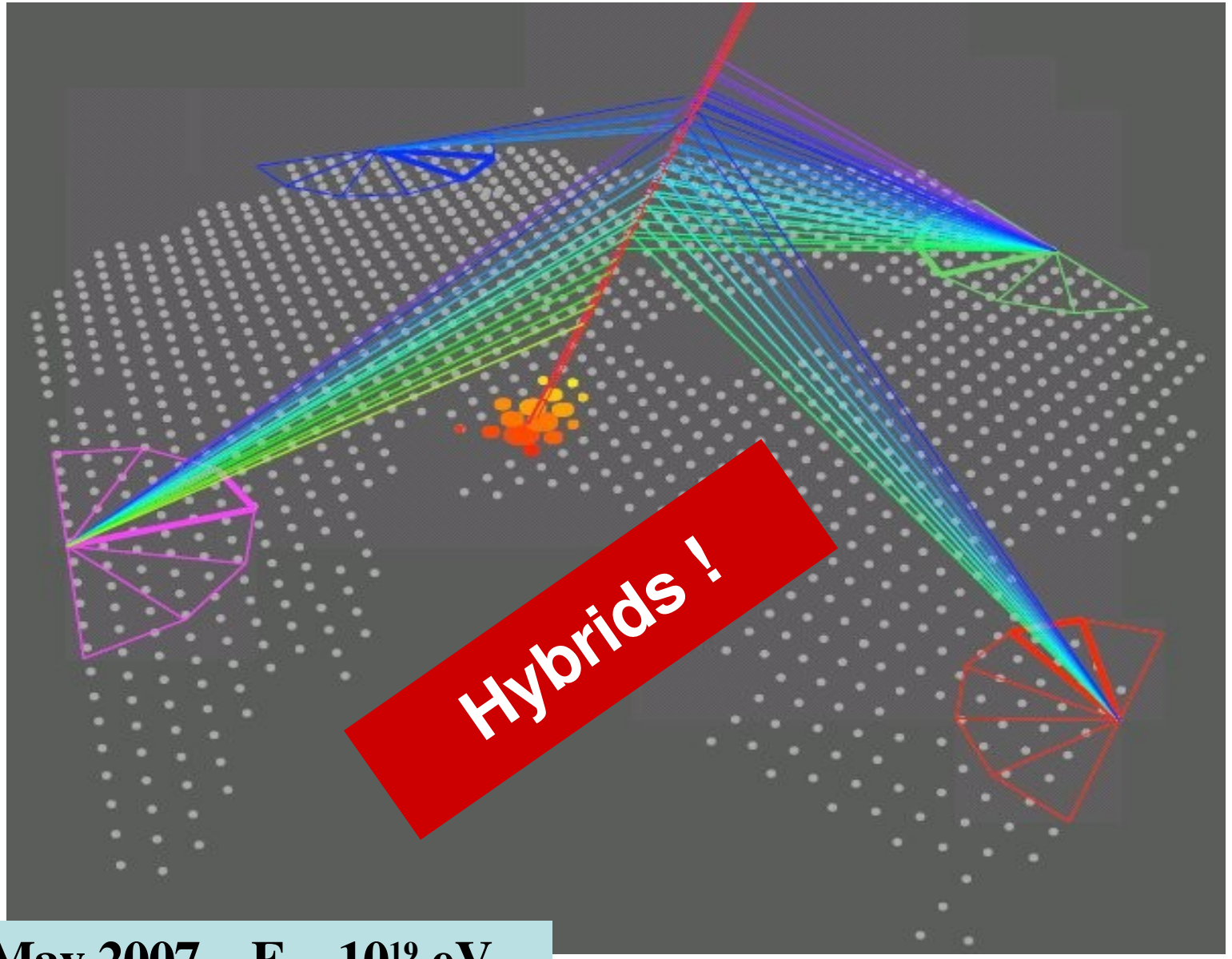


Figure 3: Lateral Distribution Function (LDF) fit

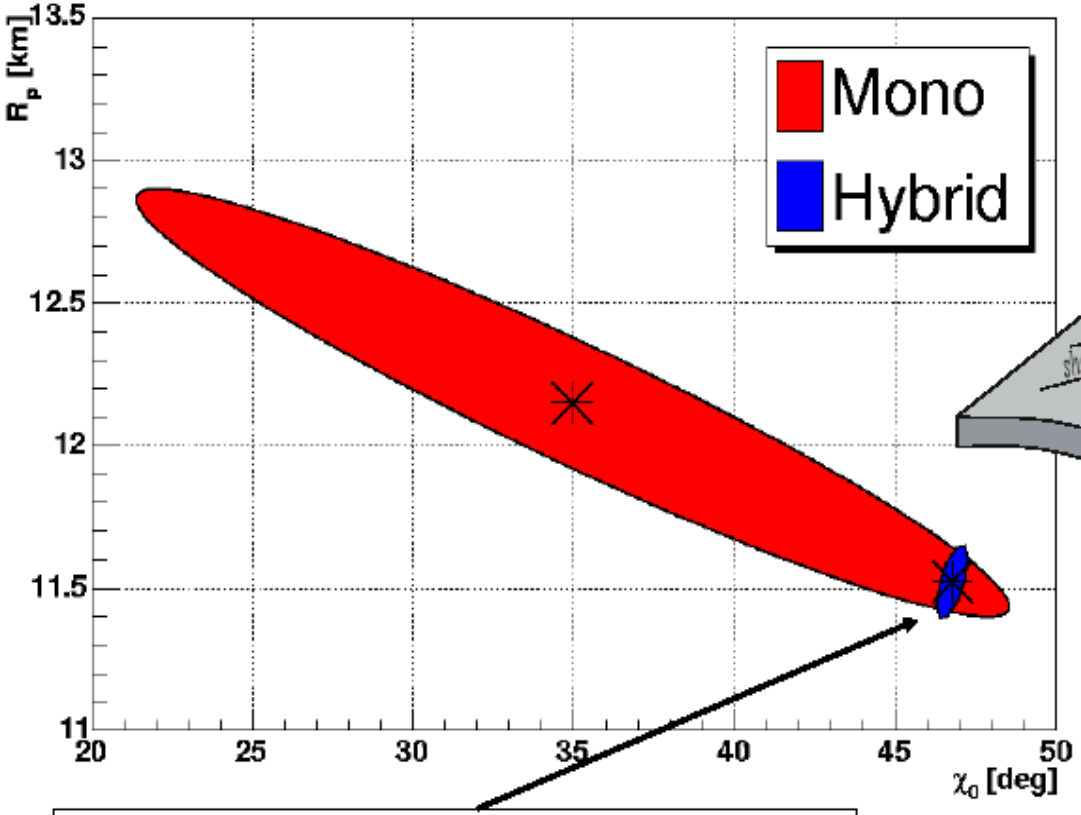
The first 4-fold stereo-hybrid

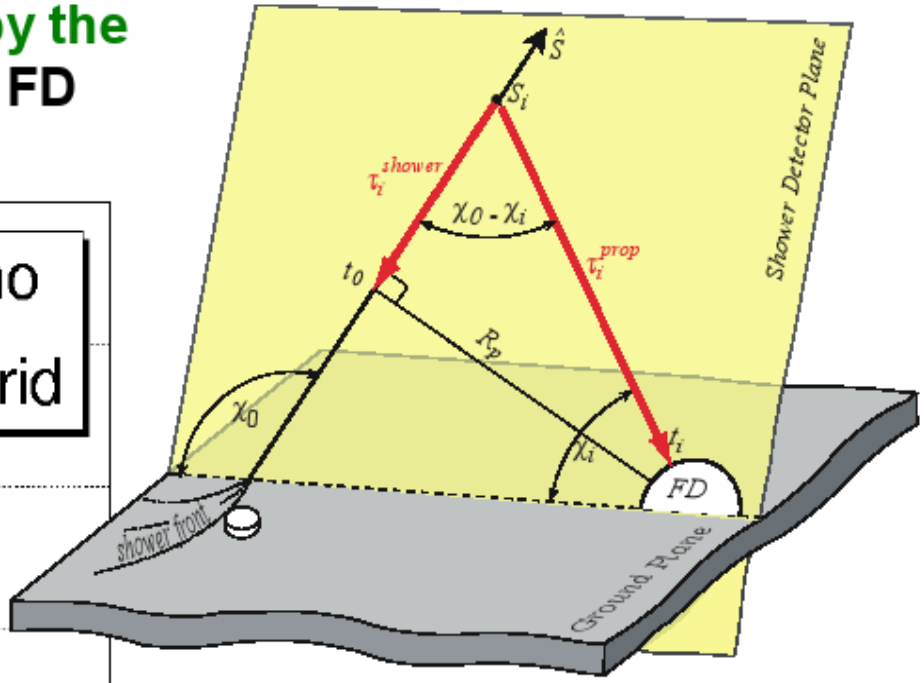


20 May 2007 E ~ 10^{19} eV

Hybrid Shower Geometry

Arrival time at ground provided by the SD, removes degeneracy in the FD geometry fit





Get T_0 from SD tank!
Geometry uncertainties shrink!

$$t(\chi) = T_0 + \frac{R_p}{c} \tan\left[\frac{(\chi_0 - \chi)}{2}\right]$$

the Power of Hybrids

	Hybrid	*SD-only*	*FD-only mono*
Angular Resolution	~ 0.2°	~ 1 - 2°	~ 3 - 5°
Aperture	*E,A, and M dependence reduced by hybrid geo.*	*Flat with energy mass (A) and model (M) free*	*E, A, and M dependent*
Energy	*A and M free*	*A and M dependent, but adopted hybrid calibration*	*A and M free*

The use of hybrids is twofold: 1. Calibration of SD events
2. Hybrid spectrum (low energy extens.)

Systematic Uncertainties

	Auger	HiRes
Fluorescence Yield	14%	11,6 { 6%
Energy loss rate		10% }
p, T, & humidity effects on yield	7%	4%
Photometric Calibration	9,5%	10%
Invisible Energy	4%	5%
Reconstruction	10%	?
Total	**21%**	**17%**

if reconstruction uncertainty is ignored: 19 %

Note: this causes an integral

flux uncertainty (γ =3.0) of: **46 %** **37 %**

(on top of effect of acceptance uncertainty)

Air Fluorescence Yield

Fluorescence yield is at present the dominant error contribution

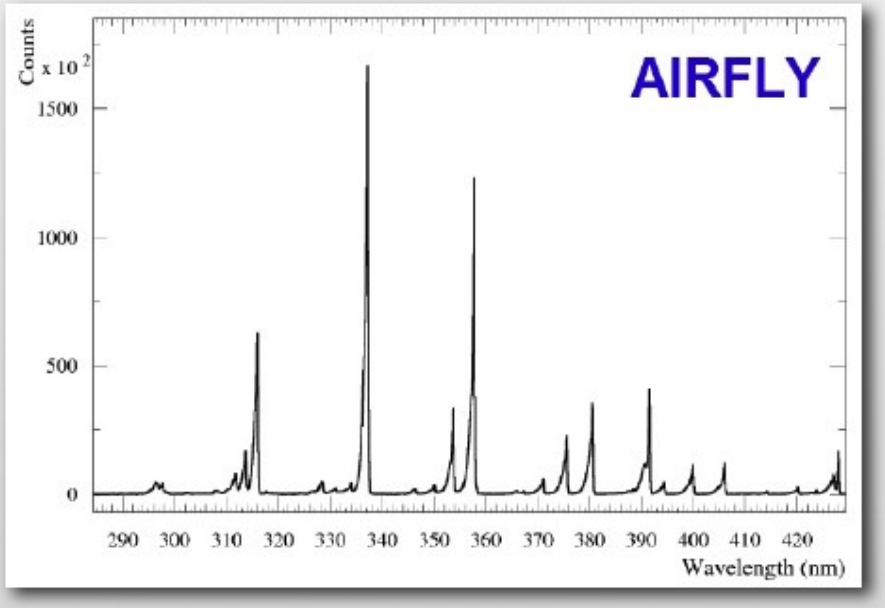
also: Auger uses Nagano et al, HiRes uses Kakimoto et al.

New (better) data will become available from:

AIRFLY using test beam at DAΦNE and elsewhere measuring p, T, and humidity dependence of abs. yield

FLASH using test beam at SLAC

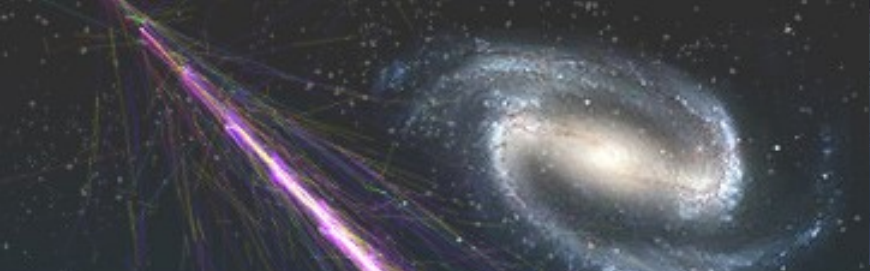
MACFLY using CERN-SPS test beam



Goal: reach 1 % level

Data on abs. yields expected to be released at workshop in Spain next week

5th Fluorescence Workshop
El Escorial - Madrid, Spain
16 - 20 September 2007




ENERGY SPECTRUM

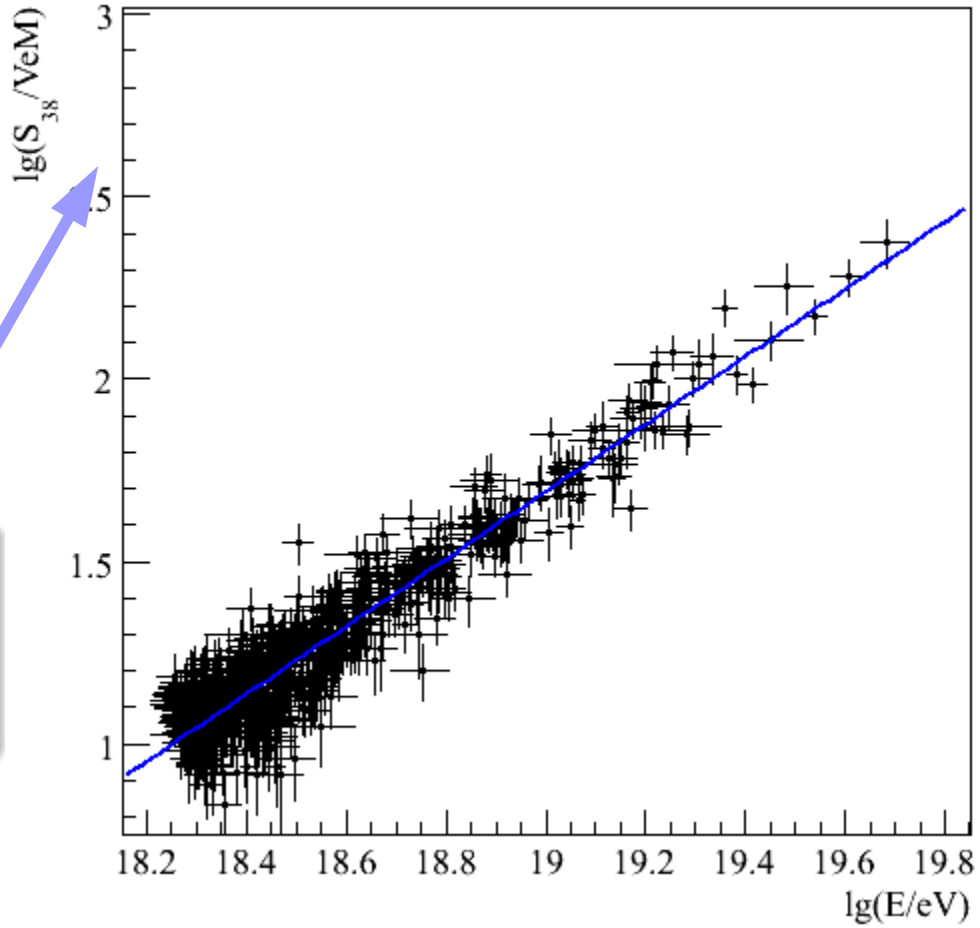
Energy Calibration

- *The most statistically significant from SD*
- *calibrated in energy by "golden hybrid" events*
- *energy systematic error ~22 %*

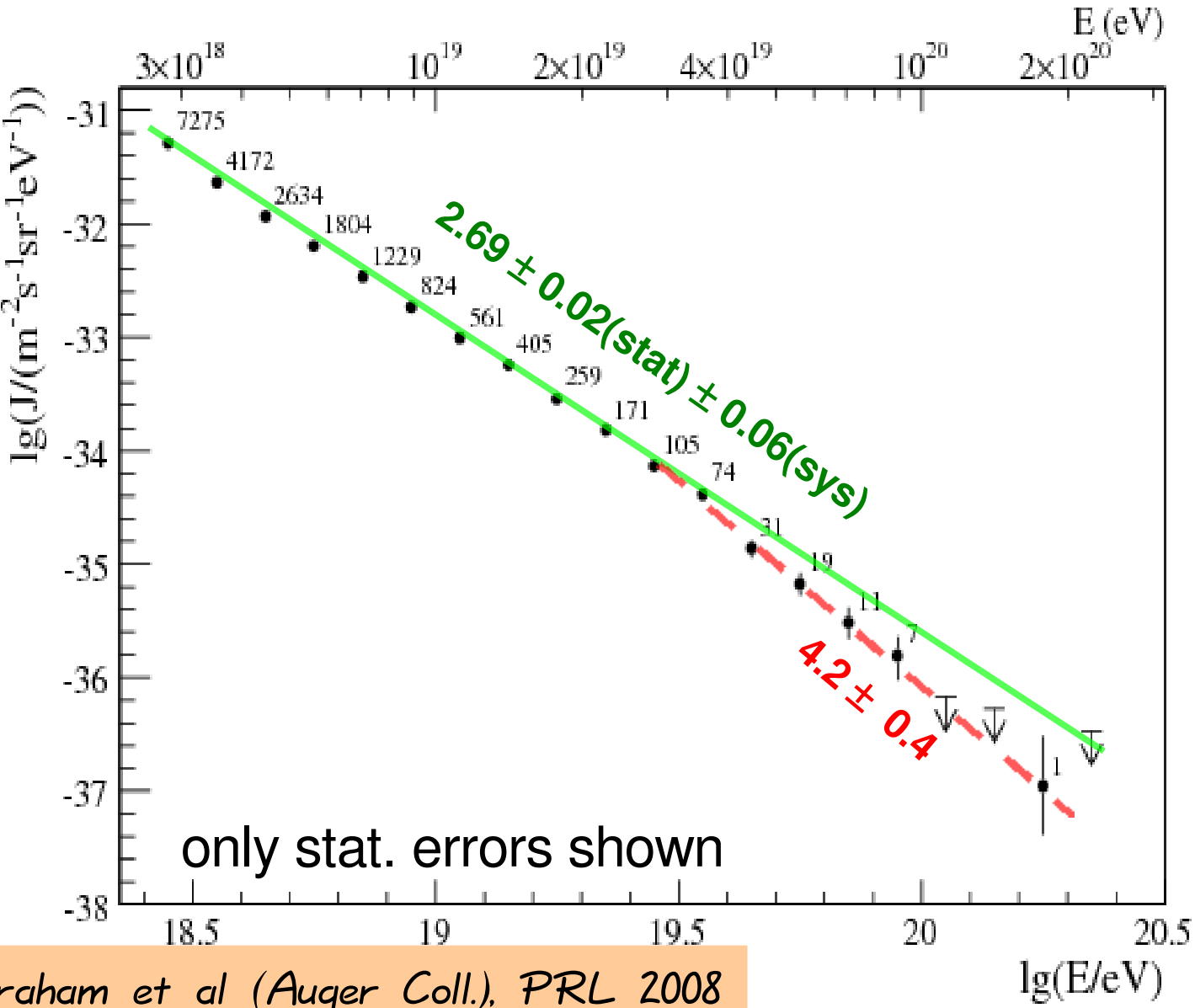
mostly from systematics of the FD detector (fluorescence yield, atmospheric transparency...)

From S(1000) to S_{38}

Need to normalize atmos. absorption
S_{38}: S(1000) of a shower at $\theta = 38^\circ$
Determined by CIC

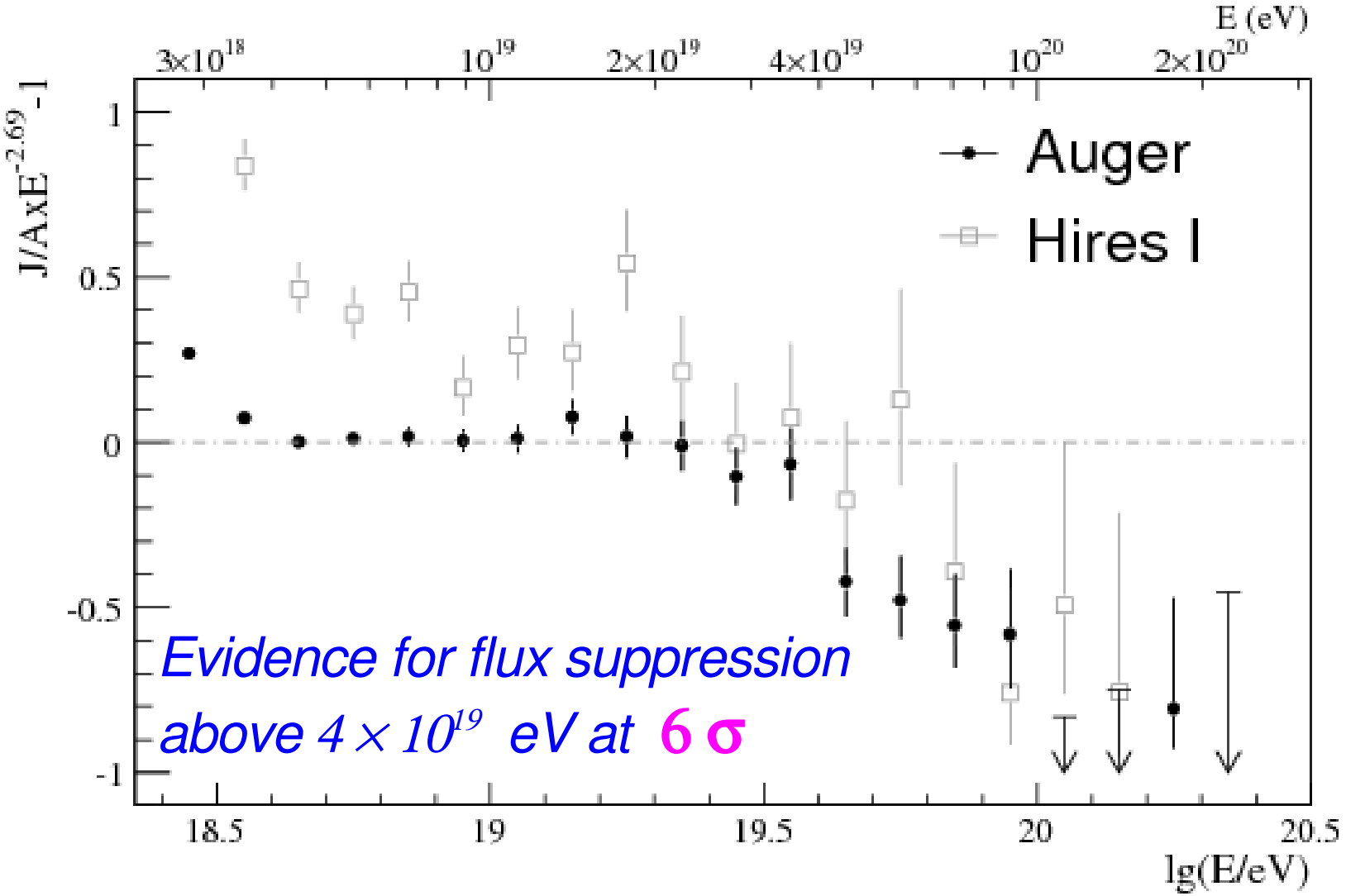


the SD Energy Spectrum

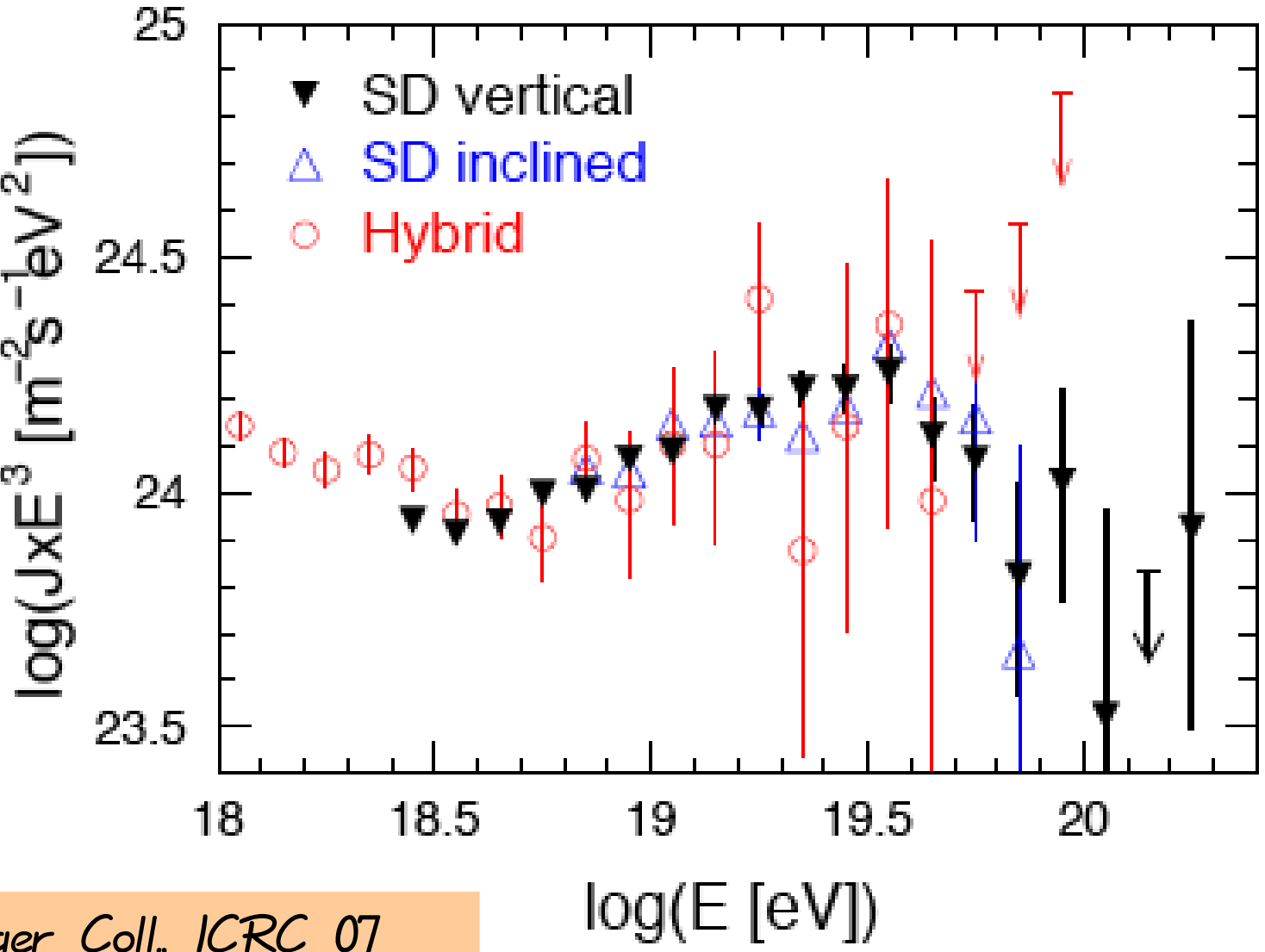


J. Abraham et al (Auger Coll.), PRL 2008

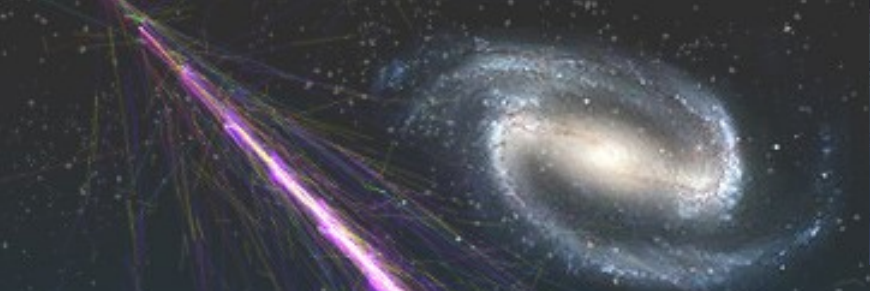
$E^{2.69} \times$ Spectrum



Combining spectra: hybrid + SD + SD inclined (>70º)

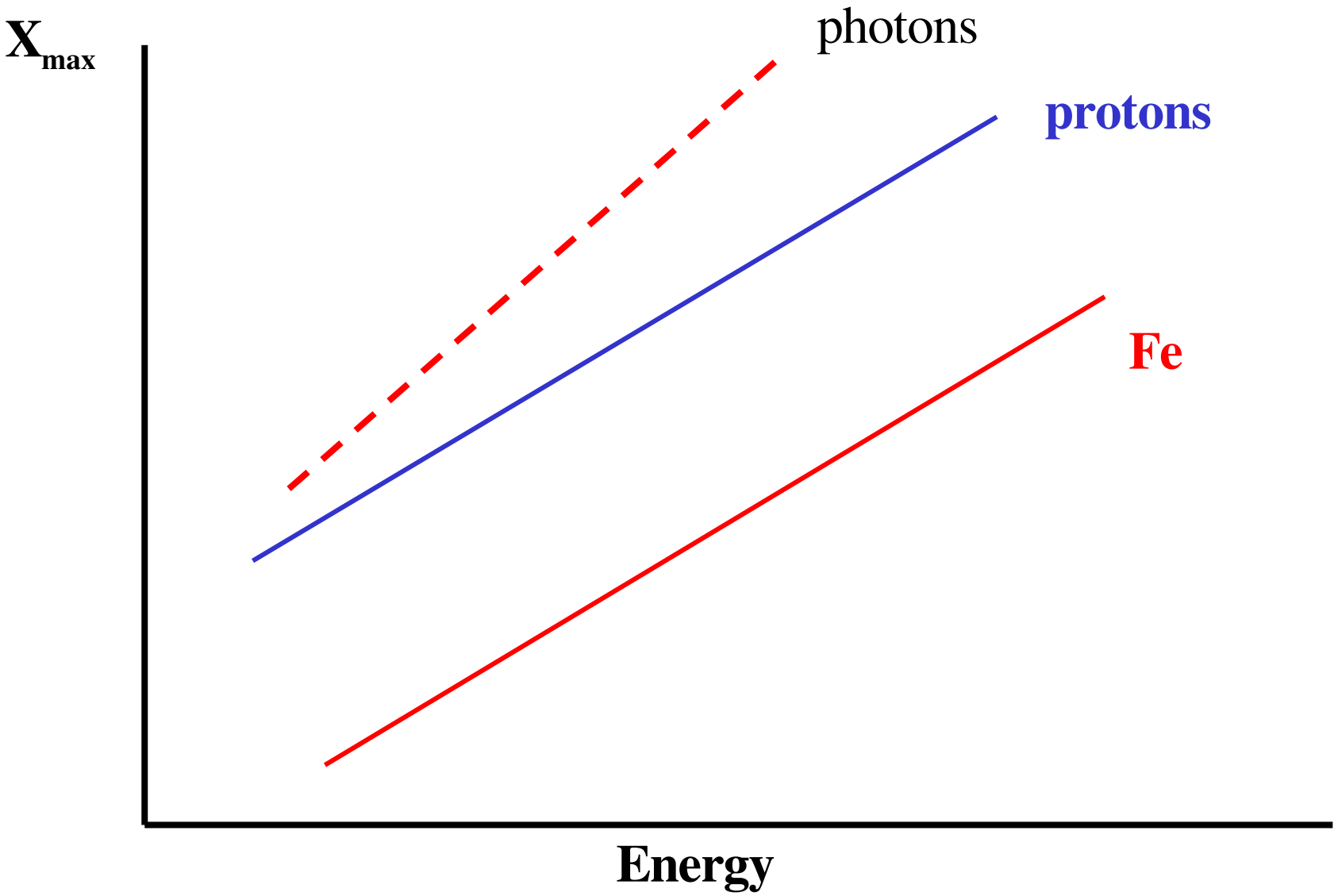


Auger Coll., ICRC 07

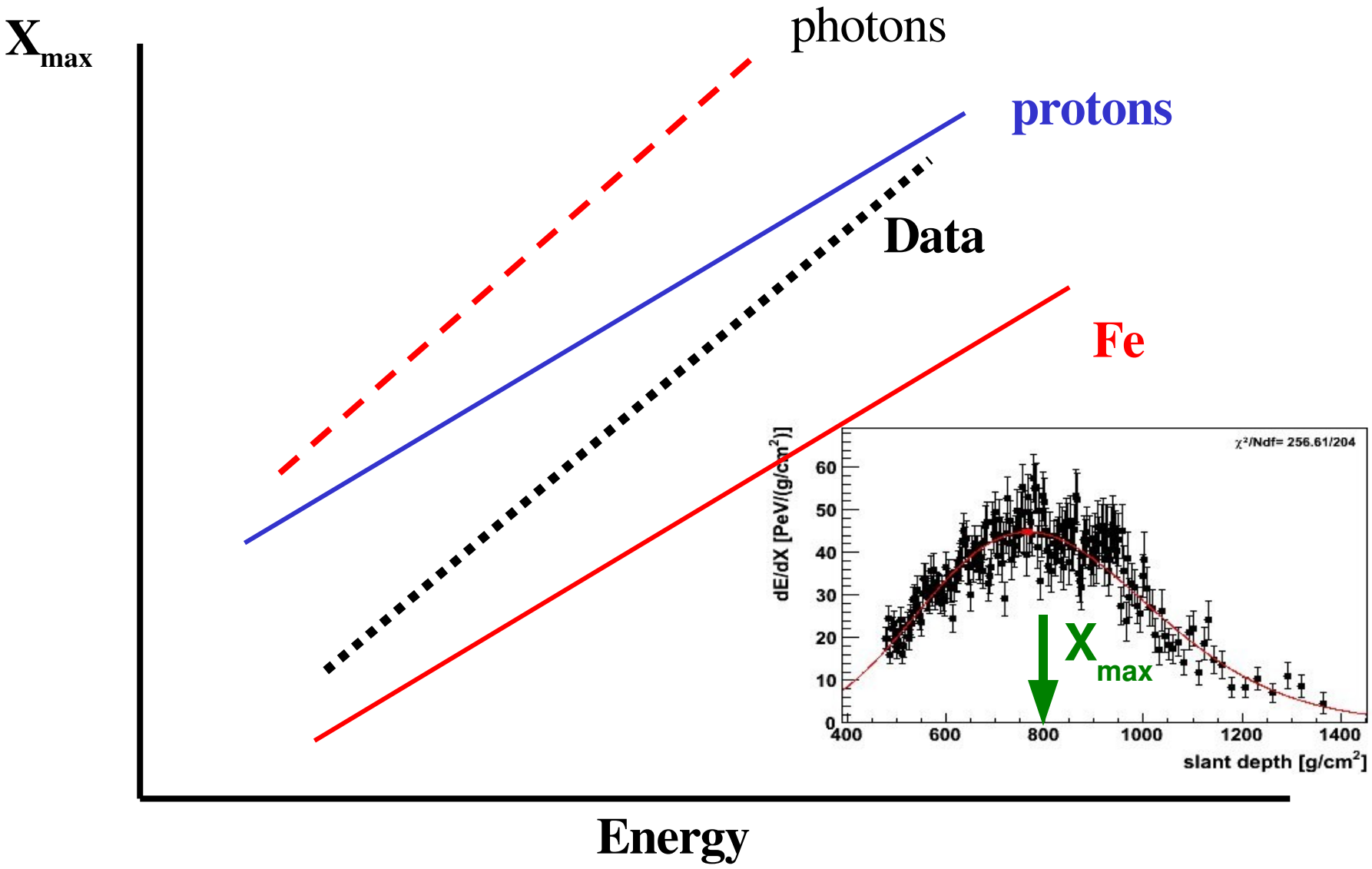



MASS COMPOSITION

Mass Composition: the principle

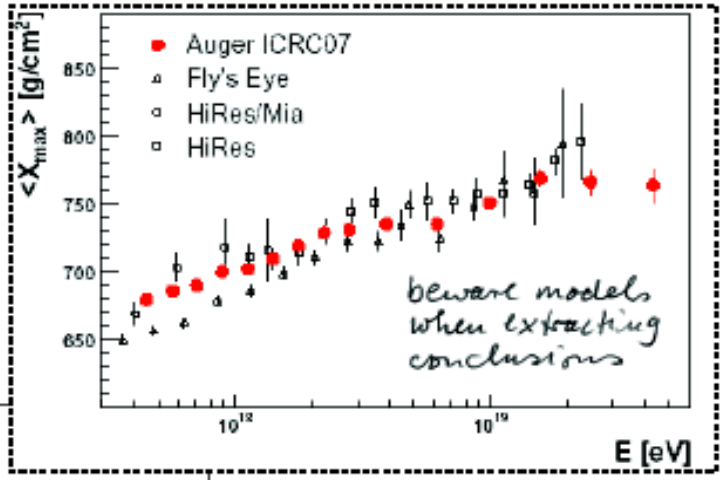


Mass Composition: the principle

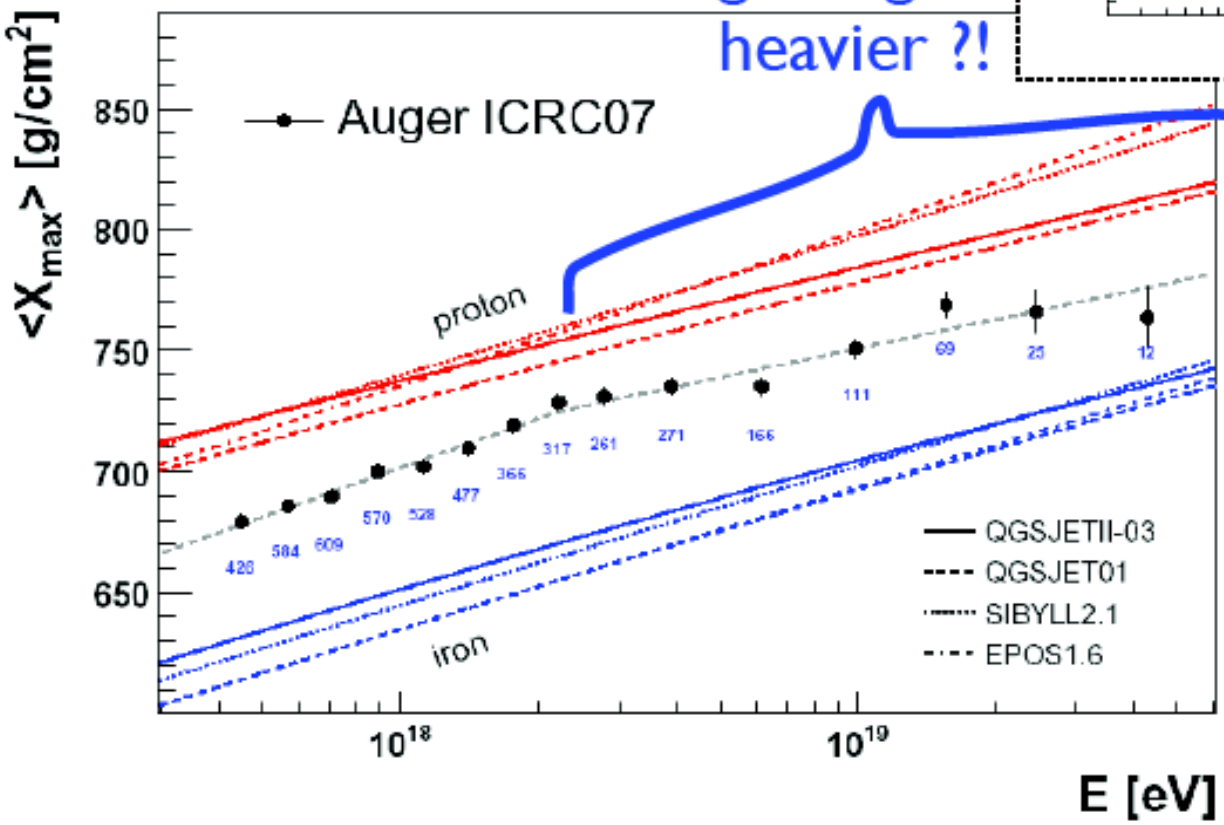


Elongation Rate Measurement

from X_{max} to primary mass



getting heavier ?!

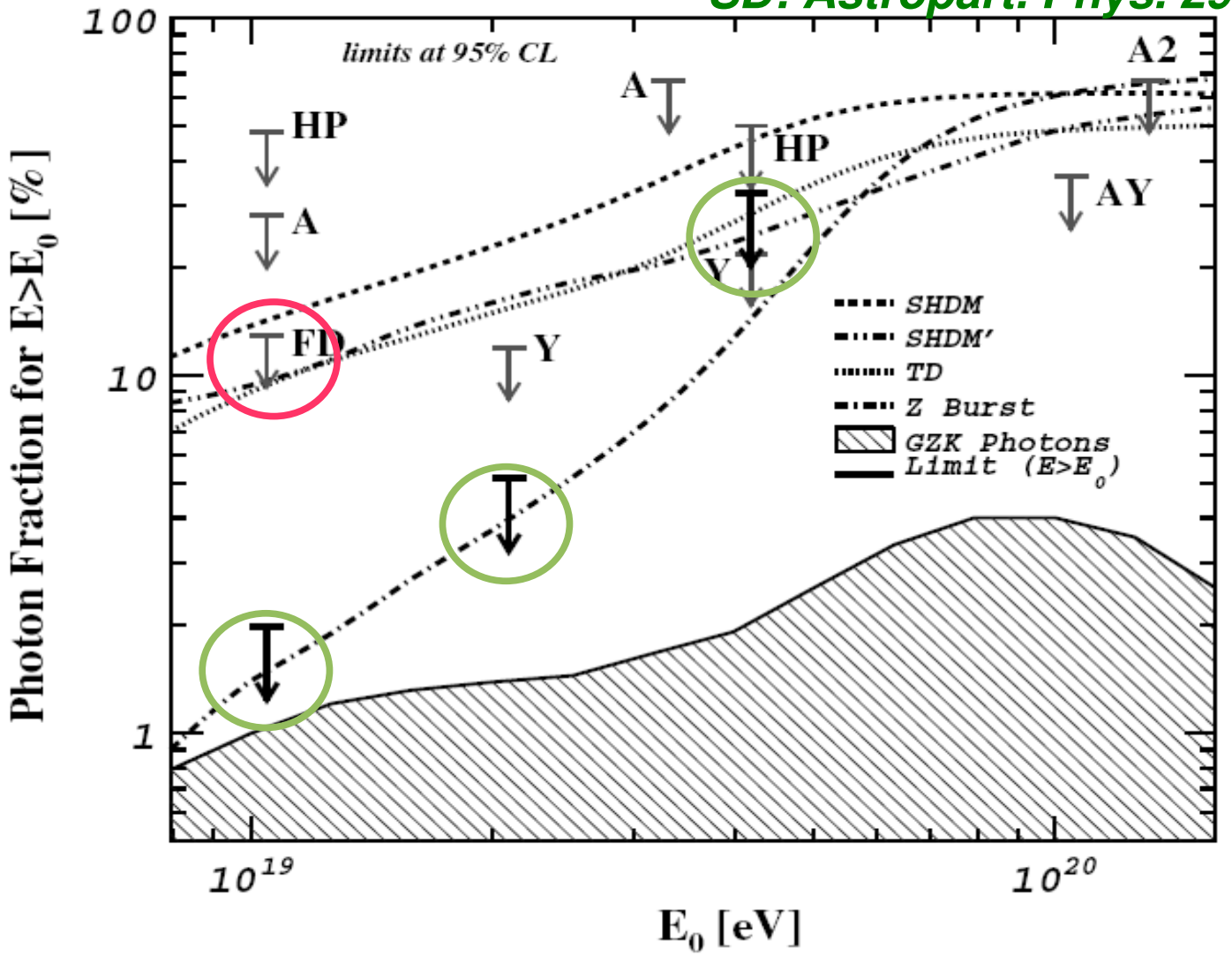


need more data here...

Photons: upper limits

SD: Astropart. Phys. 29 (2008), 243

Hybrids: Astrop. Phys., 27 (2007),155



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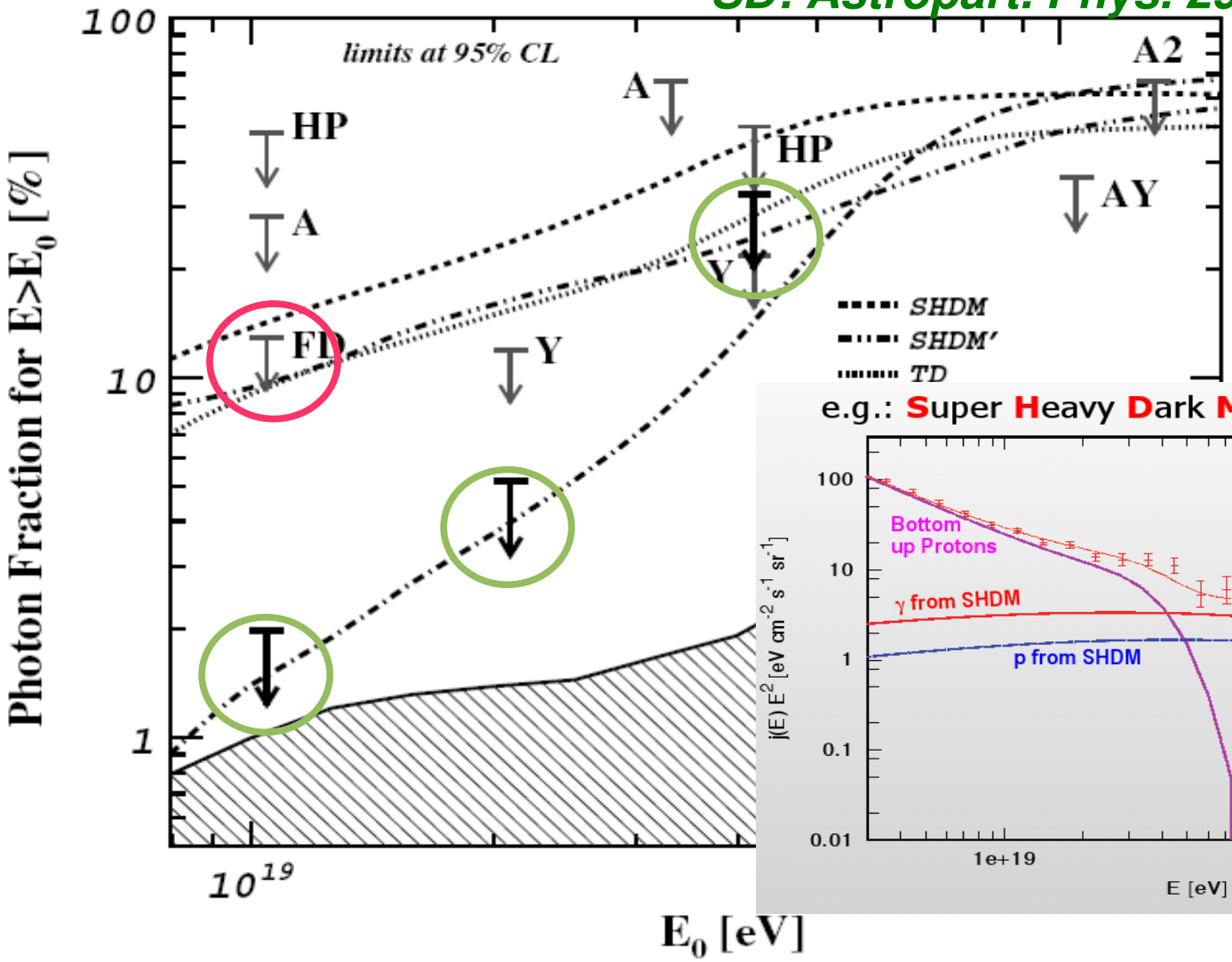
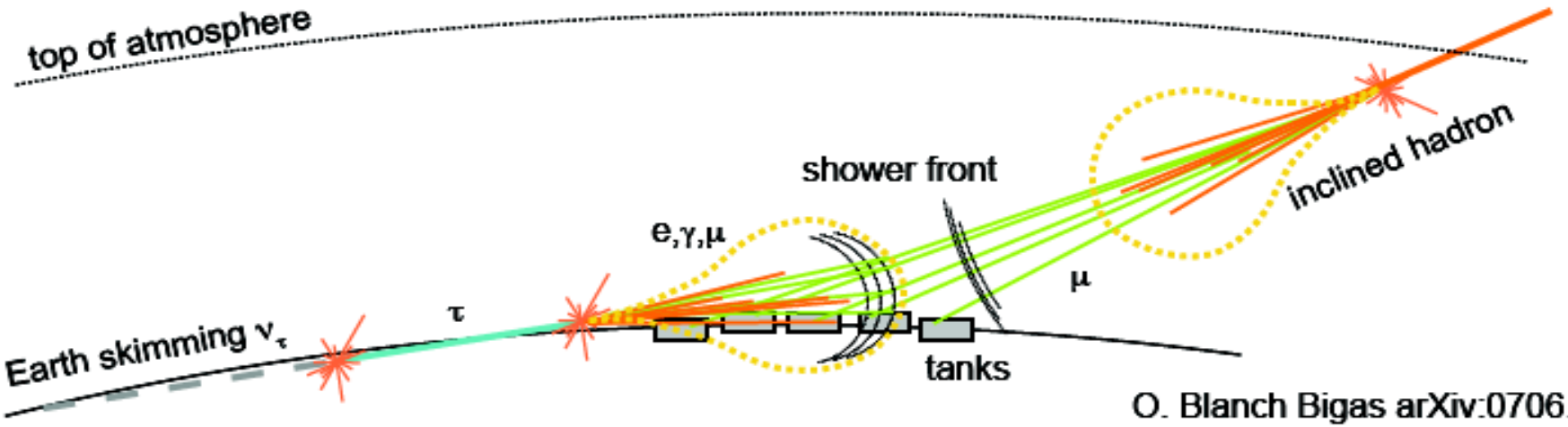


Top down models strongly constrained

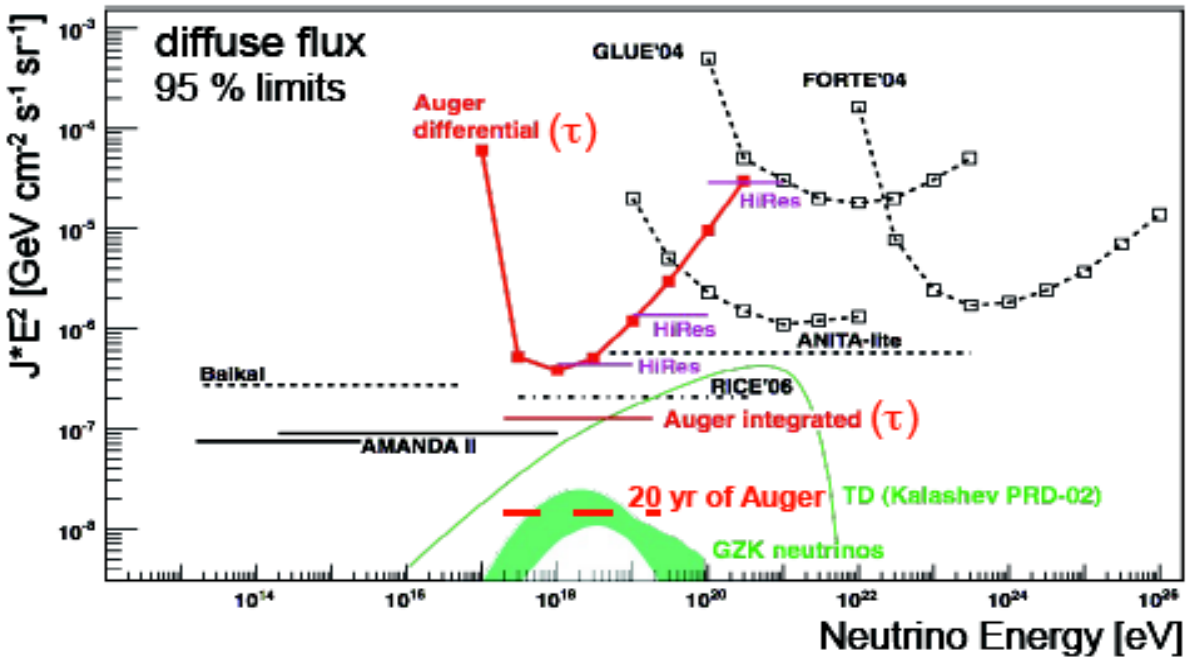
Neutrinos: Earth skimming ν_τ



O. Blanch Bigas arXiv:0706.1658

- Look for "young" horizontal showers
- SD aperture for ν_τ increased by Earth skimming

Limits comparable with dedicated experiments
Physics in reach



graphics from H. Dembinski




ARRIVAL DIRECTIONS

Initial Anisotropy Searches

Typical accuracy of reconstruction <1°

ICRC 2007

- No significant emission from Galactic Centre
- No broadband signals – e.g. Dipole – at any energy above 1 EeV
  e.g $1 < E < 3$ EeV, Amplitude < 0.7%
- No clustering of the type claimed by AGASA
- No signal from BL Lacs as possibly seen by HiRes

Summary: Previous reports have not been confirmed

UHECR Astronomy (pointing to the sources)

The promised land....

Why could it be feasible?

As energy increases, three concurrent effects:

$$\delta \simeq 2.7^{\circ} \frac{60 \text{ EeV}}{E/Z} \left| \int_0^D \left(\frac{\mathrm{dx}}{\mathrm{kpc}} \times \frac{\mathrm{B}}{3\ \mu\mathrm{G}} \right) \right|$$

- *Magnetic deflection* ↘
- *GZK: only close-by sources, R* ↘
- *Close-by Universe* ***is anisotropic***

conversely

Correlation with sources in the GZK sphere would unambiguously prove the reality of the cutoff (and give hints on the nature of sources)

Search for point sources: the method

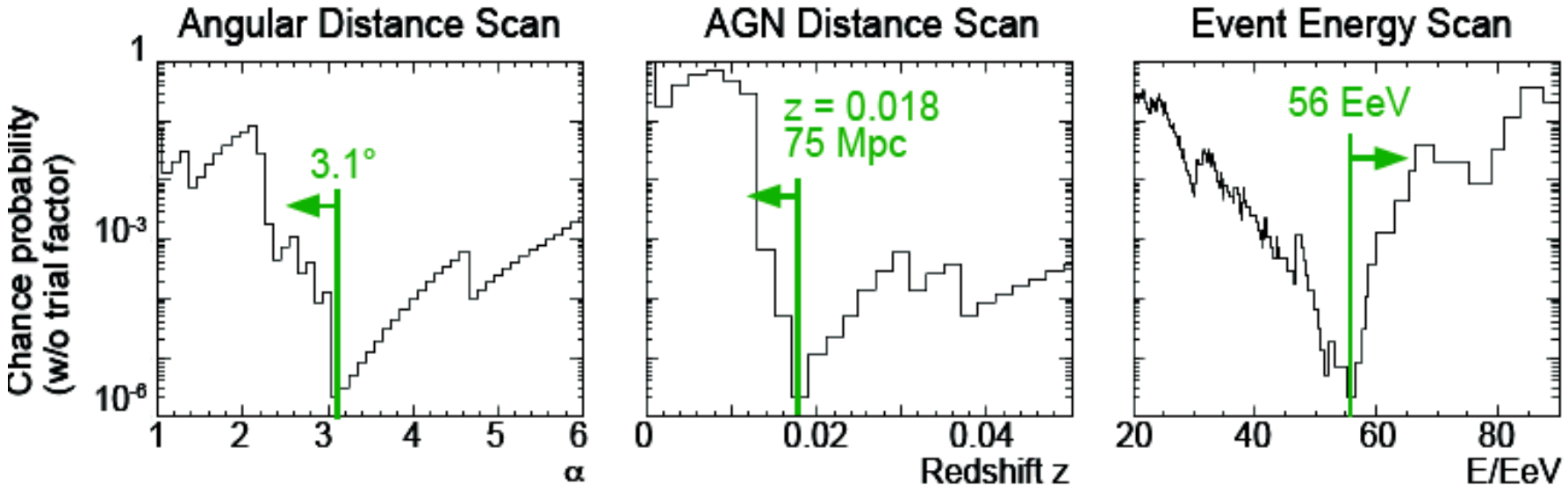
- Need to search correlations of a selected sample of events with astrophysical objects.... ***which? how?***
- Large parameter space: events -> ***Energy, angular aperture***
  Sources -> what sources: ***type, distance (z)...***
- Method: ***perform a scan in the parameter space***, after having chosen sources of a given type from a catalogue
- Chosen ***Veron-Cetty, Veron Catalogue of AGNs*** (12th ed.)

VC-V catalogue:
85,221 QSO - 1,122 BL Lac - 21,737 AGN.
694 with z < 0.024 (~100 Mpc)
z > 0.024 increasingly incomplete and in-homogeneous.

Search for point sources: the path

Strategy to avoid *a posteriori* signals:

- Exploratory scan to find the best search parameters
- Freeze parameters
- Confirm result with new data (*a priory search)*
- *Prescription* fulfilled when chance probability ≤1%



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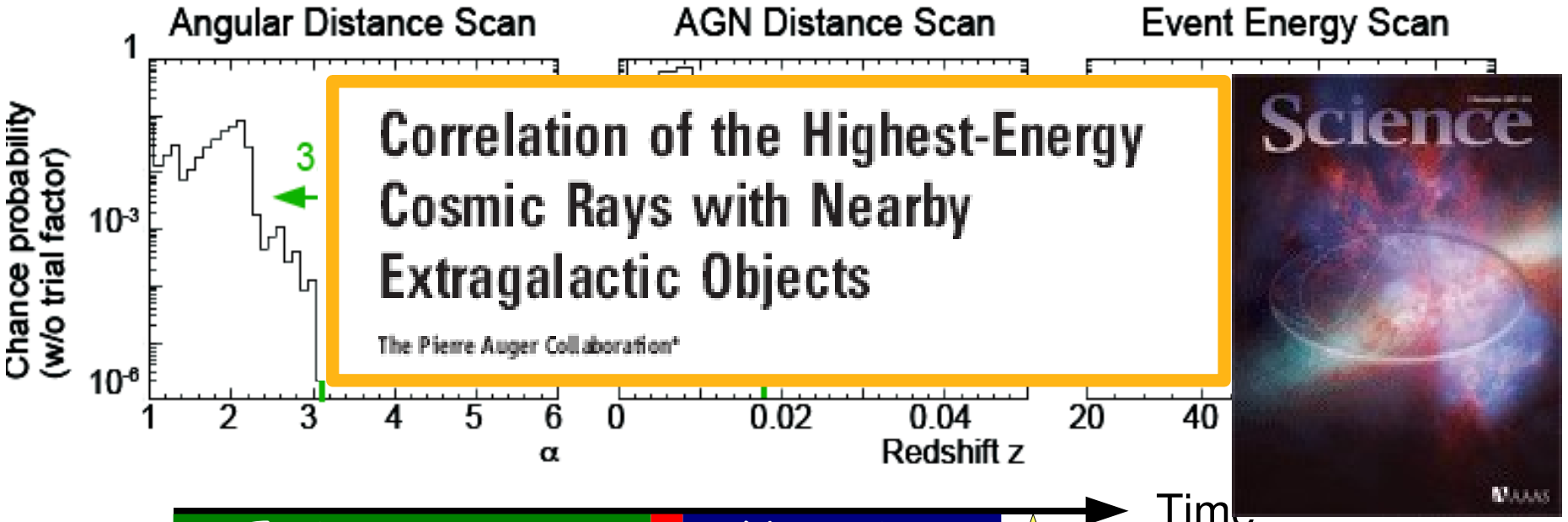
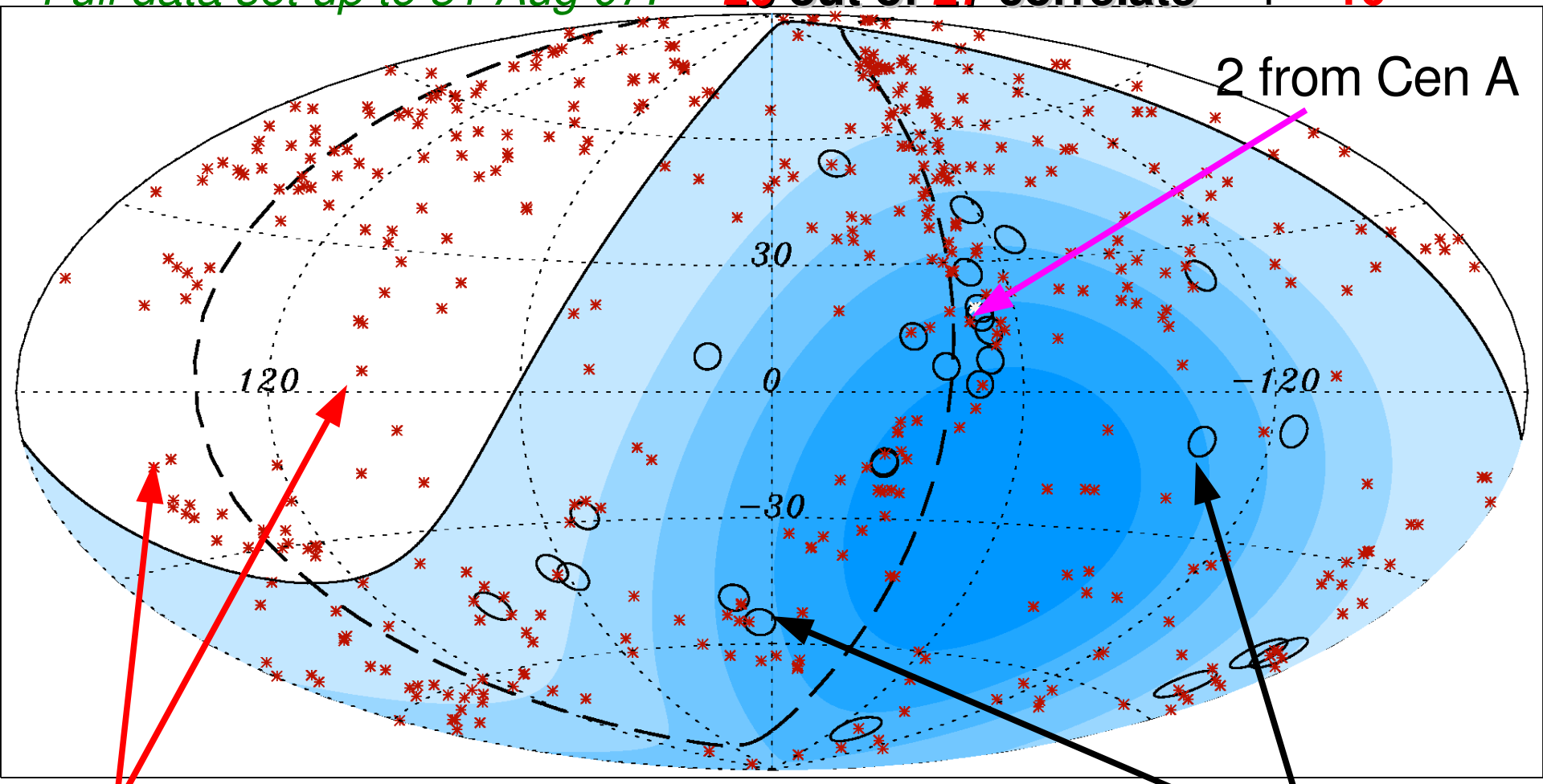


Correlation with nearby AGNs

Full data set up to 31 Aug 07: **20 out of 27 correlate** P ~10^{-5}

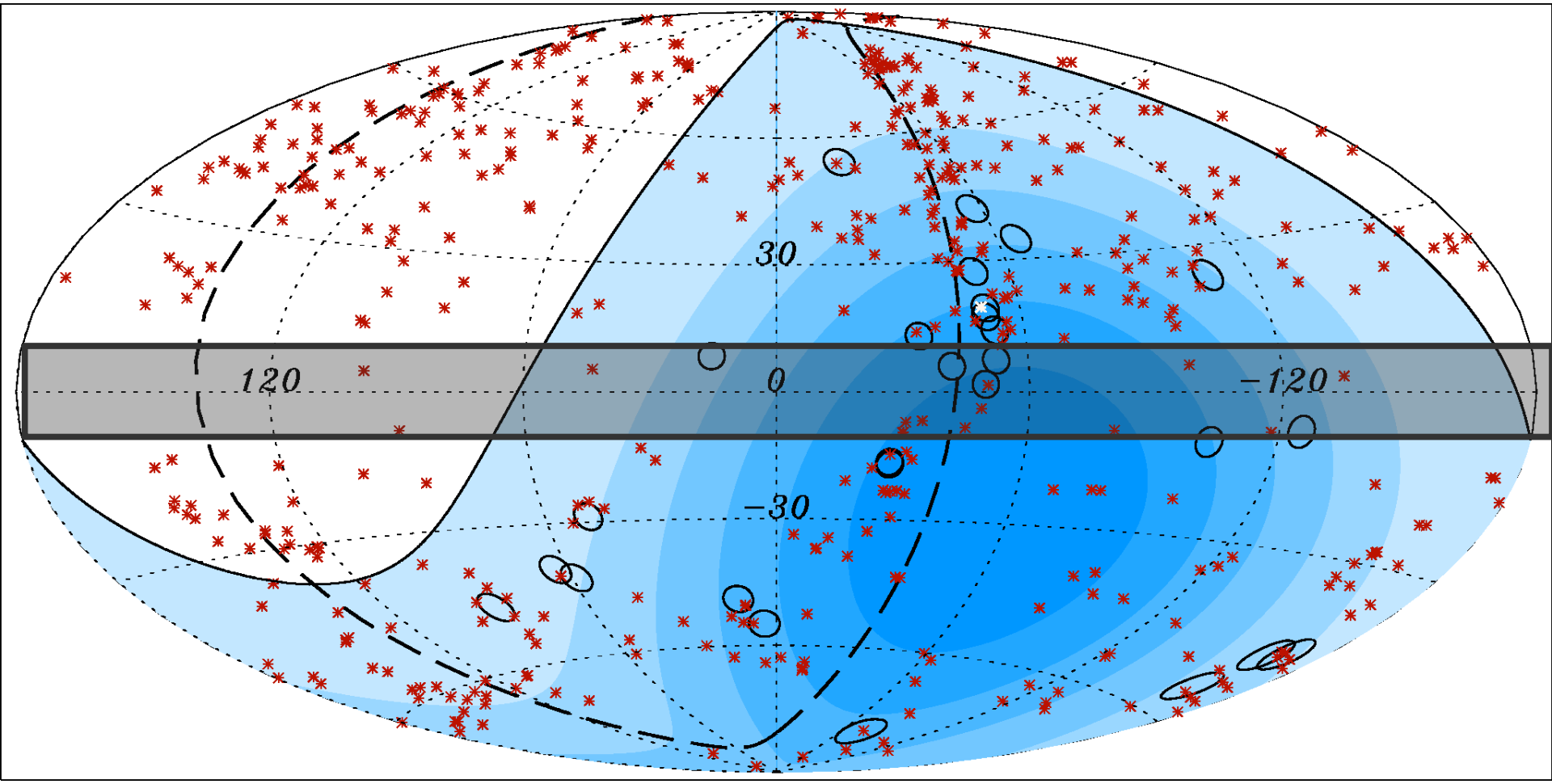


✶ AGNs from VC-V cat. (z<0.018)

darker color ➔ larger exposure

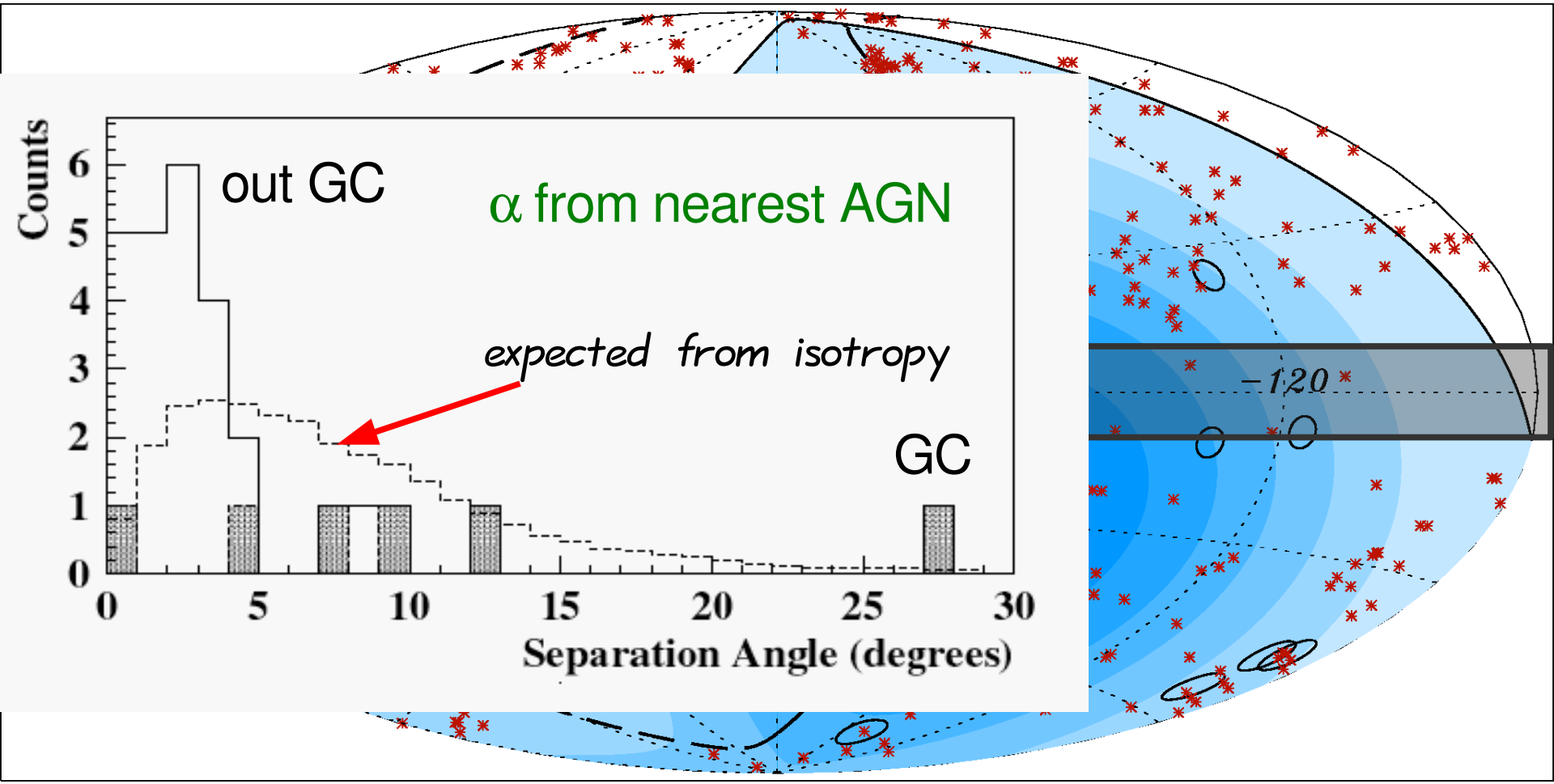
O Auger events

Galactic plane cut: |b| > 12º



19 out of 21 do correlate

Galactic plane cut: |b| > 12°



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Open issues and future directions

- AGNs: sources or tracers?
  - *other catalogues (IRAS, Abell,REFLEX, NORAS)*
  - *50+ papers about Auger correlated events (several alternative explanations)*
  - *HiRes events not correlating: 2/13* (arXiv:0804.0382)
  - *Mass composition*
- Establish anisotropy through catalogue-independent methods
  - *several searches currently undergoing*
  - *comparison among algorithms*

What's coming next?

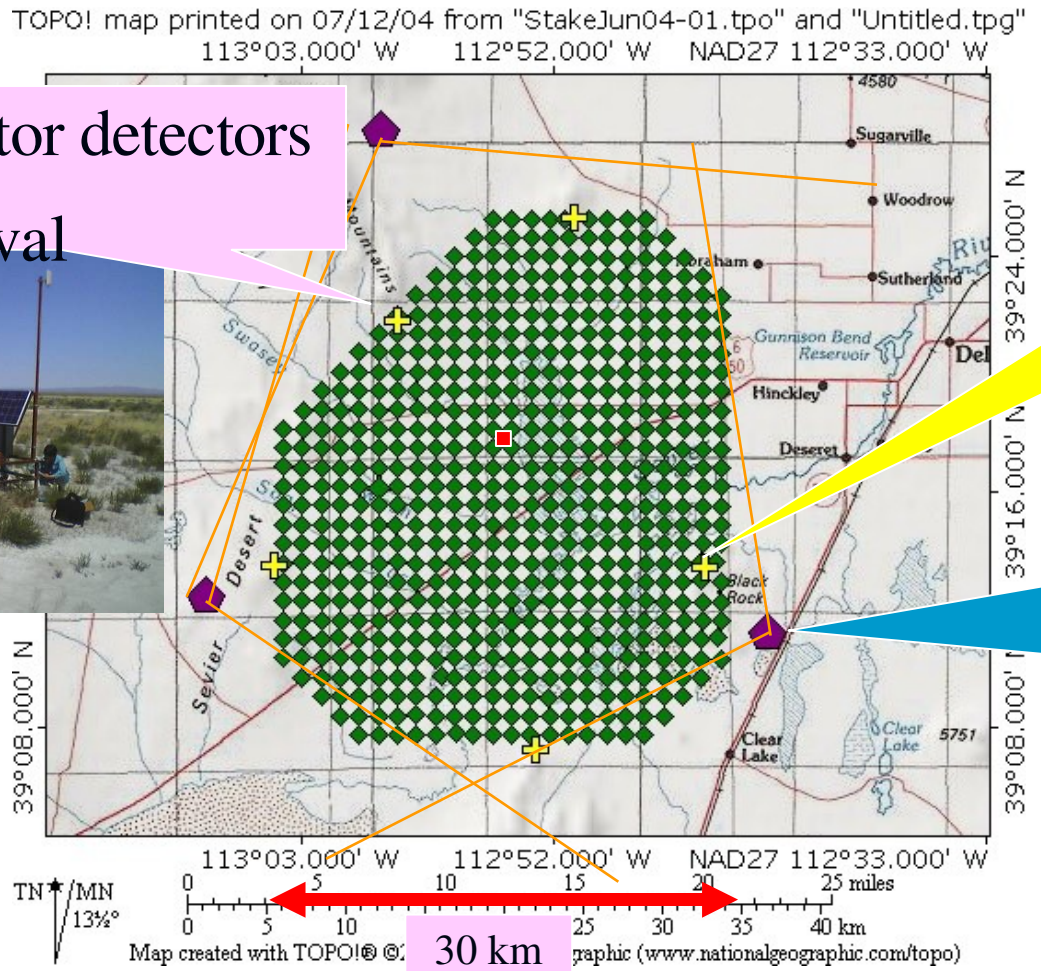
- A new observatory: TA (Telescope Array)
  + low energy extension TALE
- Auger South: low energy extension
  HEAT (3 high elevation telescopes)
  AMIGA (SD infill + muon detectors)
- Auger North: site chosen Lamar (CO)
  undergoing final design review

Phase-I TA project

Millard County, Utah, USA Altitude ~1400 m

576 scintillator detectors

1.2 km interval

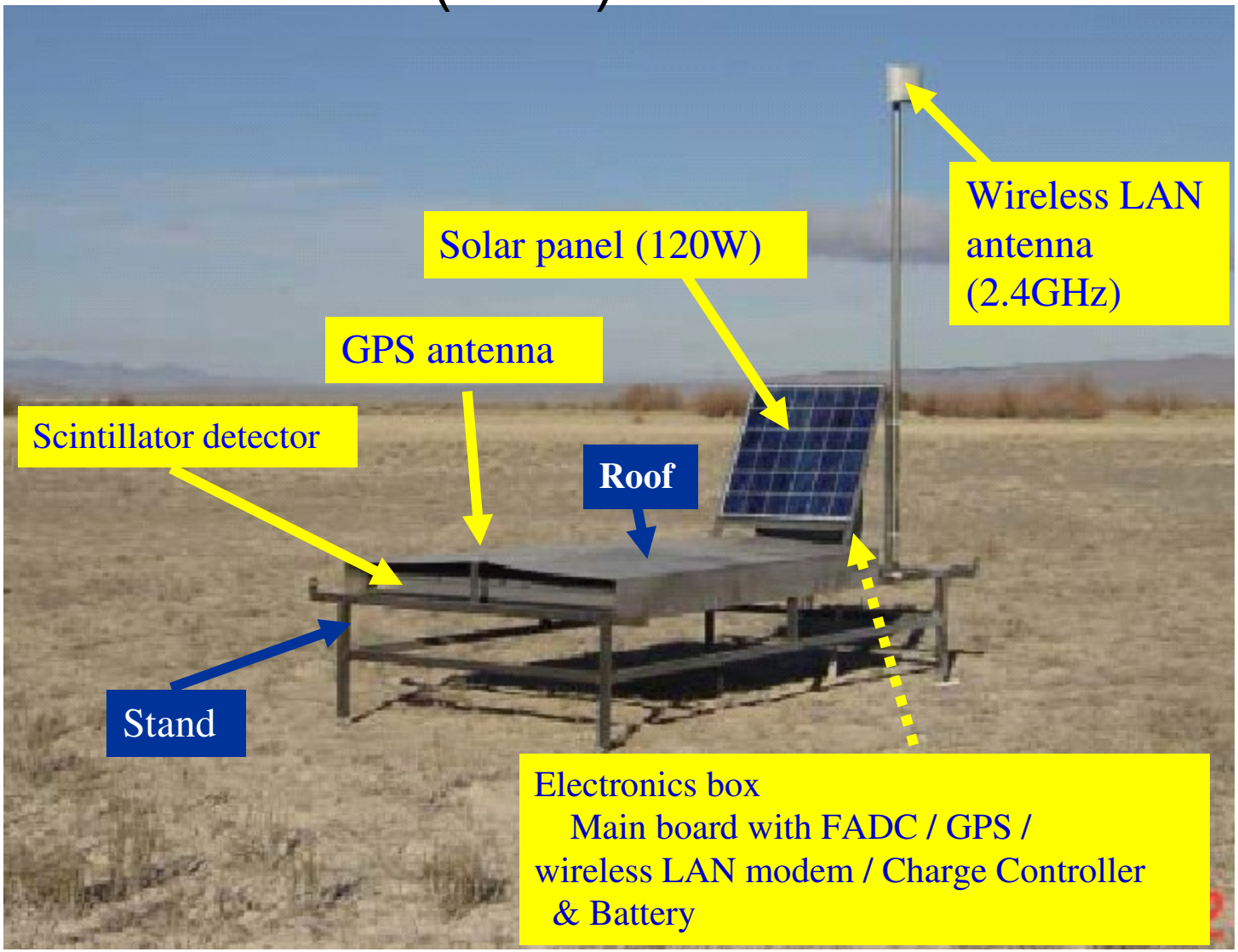


30 km

3 (+2) Communication Towers

3 FD stations (atmospheric fluorescence telescopes)

Surface Detectors (SD)



Deployment of SDs

- Completed surveys for animals, vegetation, and heritage in TA site requested by Burea of Land Manager
- Constructed 3 communication towers in September

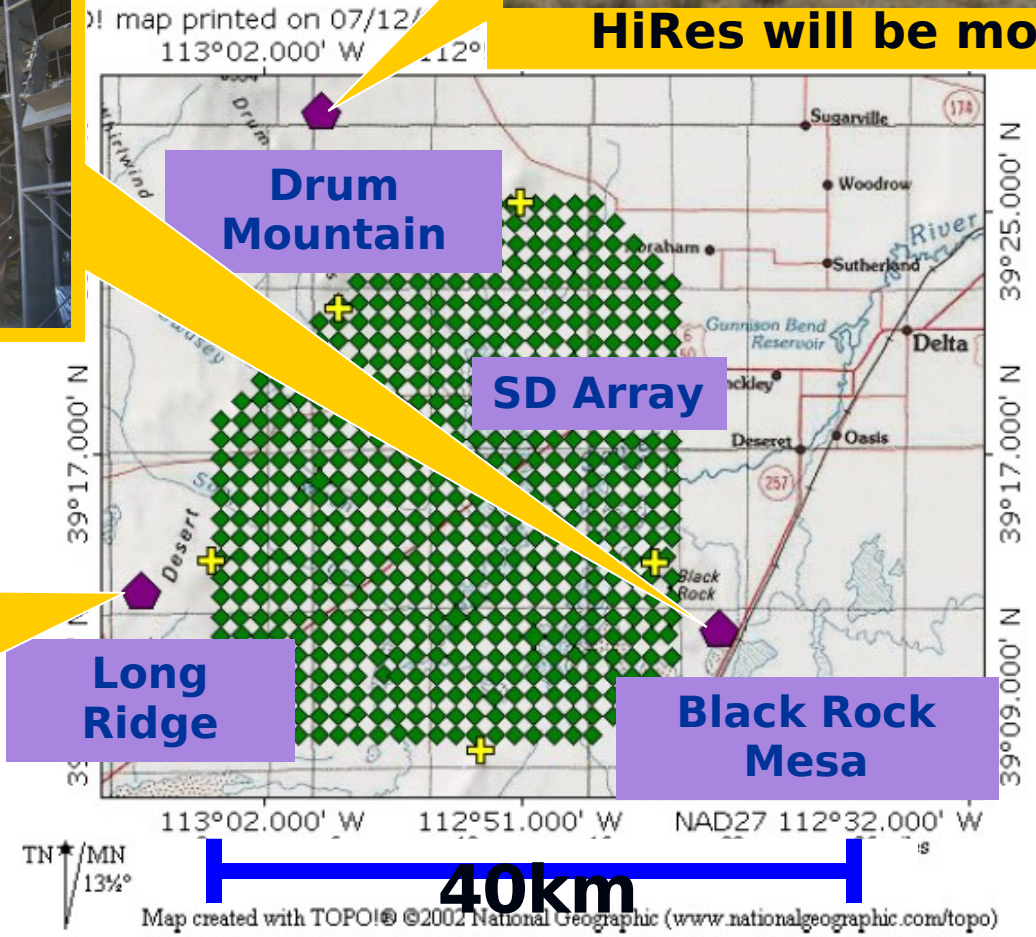
- Deployment of SDs by helicopter
  - Deployed 50 SDs in October
  - Deployed 50 SDs in December
  - Deployed 70 SDs in January
    - Deployed 170 SDs among 512 SDs by then

  - **How many SDs would be deployed by the dead line, Feb. end ?**
    (only one month left at the time)
    - Deployment by helicopter is prohibited between March 1 and August 31 in principle.

H. Sagawa, Aspen Meeting

Construction of FD buildings

HiRes will be moved.



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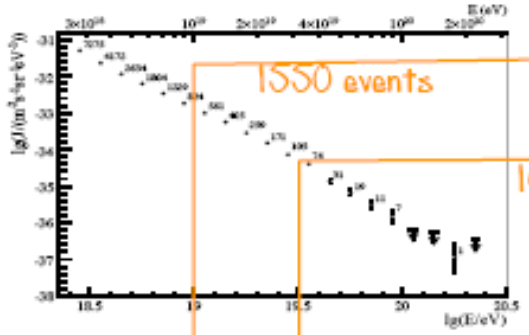
Auger North Configuration

4400 SDs

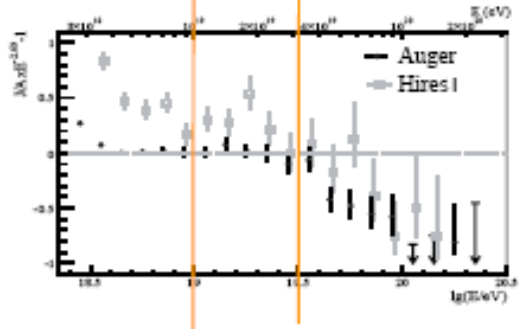
- 4000 SDs at √2*1 mi = 2.3 km spacing
  - 8000 mi^2 = 20000 km^2
  - **fill the space available!**
  - angular resolution...
  - efficiency 50% at 10^{19} eV
- 400 SDs
  - 10% area infill array
  - sqmi-sub-grid
  - 800 mi^2 = 2048 km^2
  - efficiency 100% at 10^{19} eV

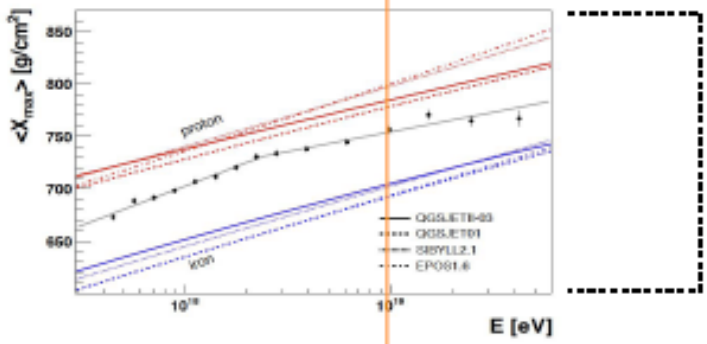
~42 FDs in 7 stations

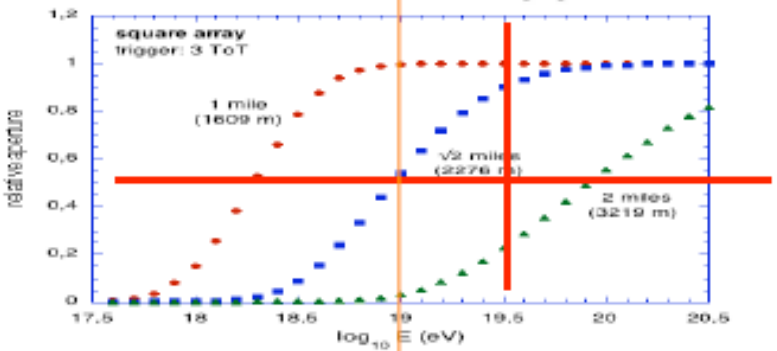
- **particle physics!**
- 40 km viewing distance
- HEAT-simplified design, cover infill area
- calibration

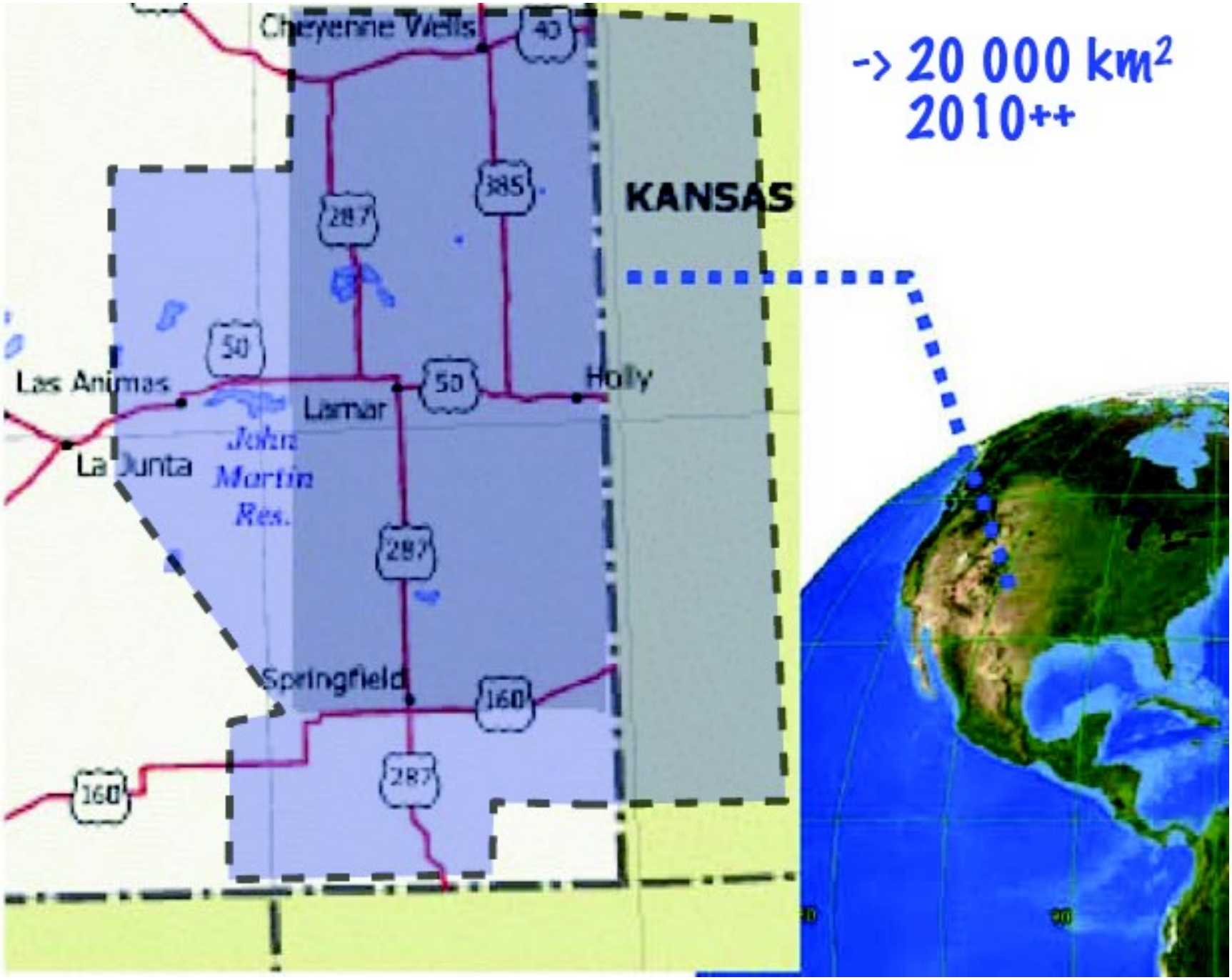


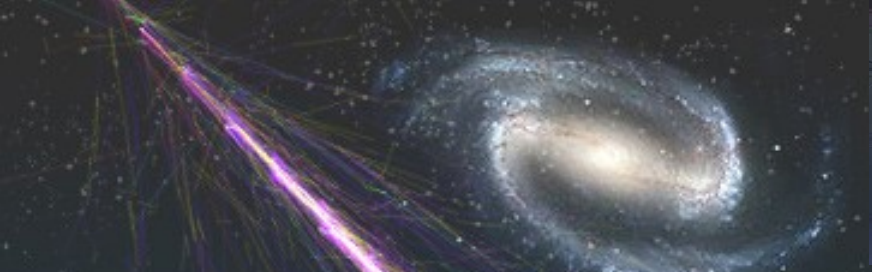
Auger South in 1.5 years (plots to be published)








Cheyenne Wells
40
385
287
KANSAS
50
Las Animas
Lamar
50
Holly
La Junta
John
Martin
Res.
287
Springfield
160
160
287
-> 20 000 km²
2010++




Summary and outlook

- *GZK established (seen by HiRes and Auger)*
- *Top-down models ~ ruled out*
  by photon & neutrino upper limits
- *Trans-GZK events correlate with nearby sources*
  Birth of UHECR astronomy (?)
- *... but several puzzles,*
  need more data and better understanding
- *The best is still to come!*