RICAP 2011 – Roma

25 May 2011

Review on High Energy Cosmic Rays

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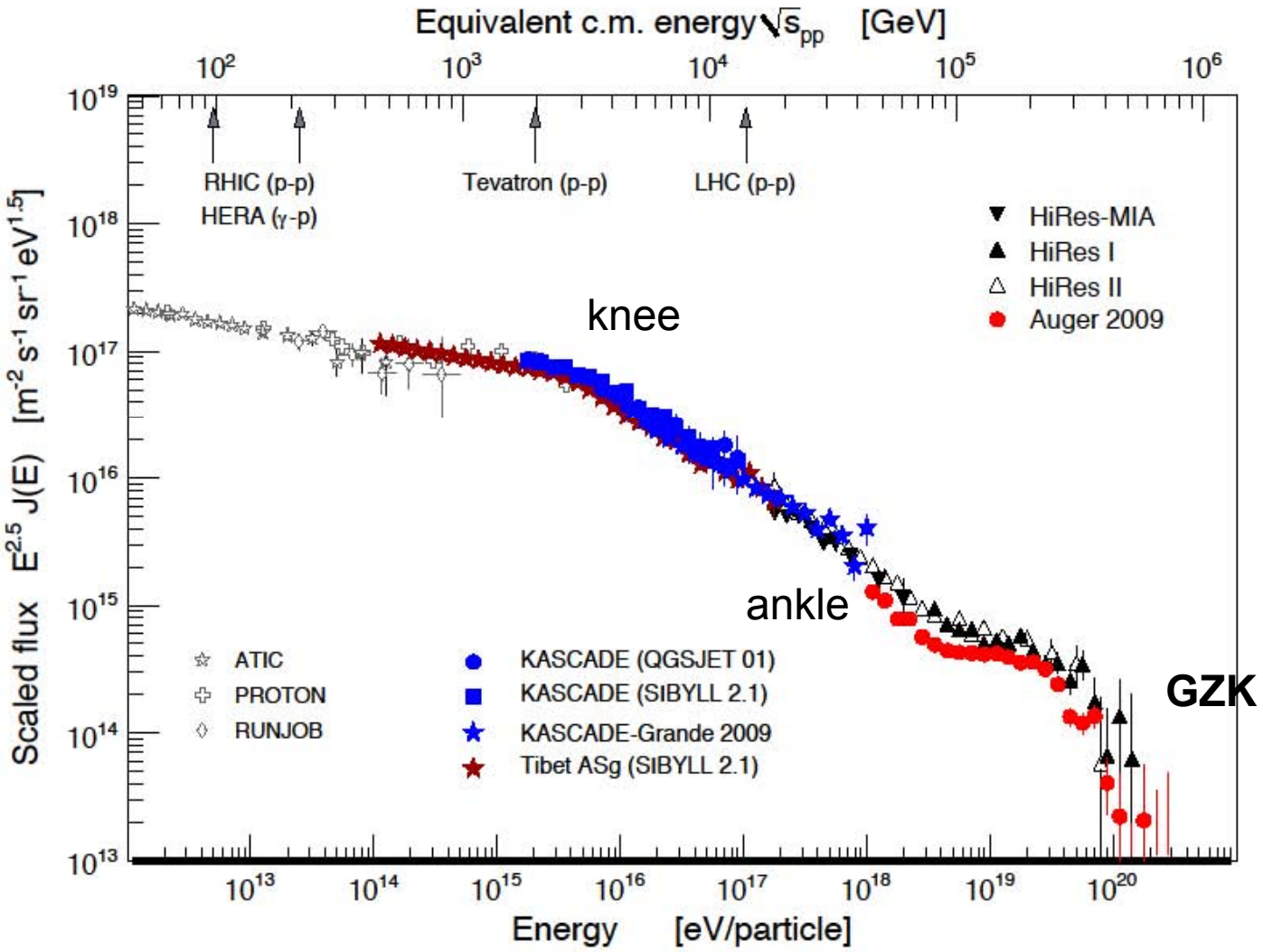
University and Sezione INFN of Roma Tor Vergata

Current status of all-particle flux



Two main experiments for the study of the high-energy region

-The Auger Observatory in the Southern hemisphere

- Telescope Array in the Northern hemisphere

Auger / TA hybrid detectors

Fluorescence Detector (FD)

N_2 molecules (300-400 nm)

- **Longitudinal development of the shower**
- **Calorimetric measurement of the energy**

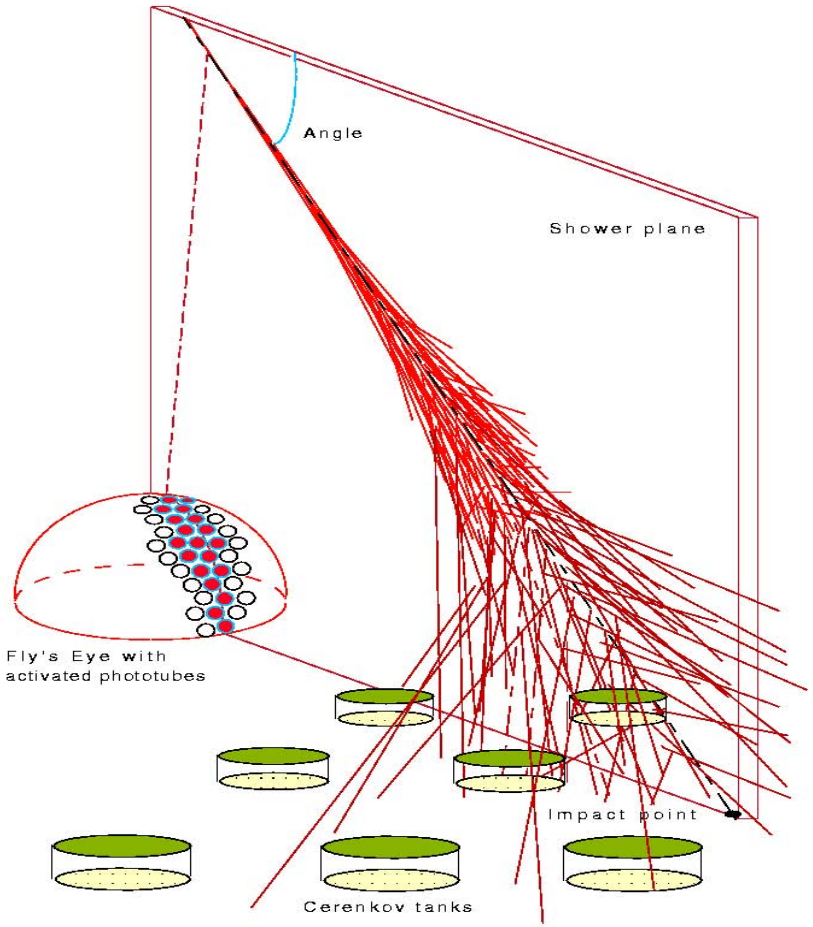
Calibration of the energy scale

- **Only moonless nights**

  ~ 10% duty cycle !

Surface Detector (SD)

- **Front of shower at ground**
- **Direction and "energy" of the shower**

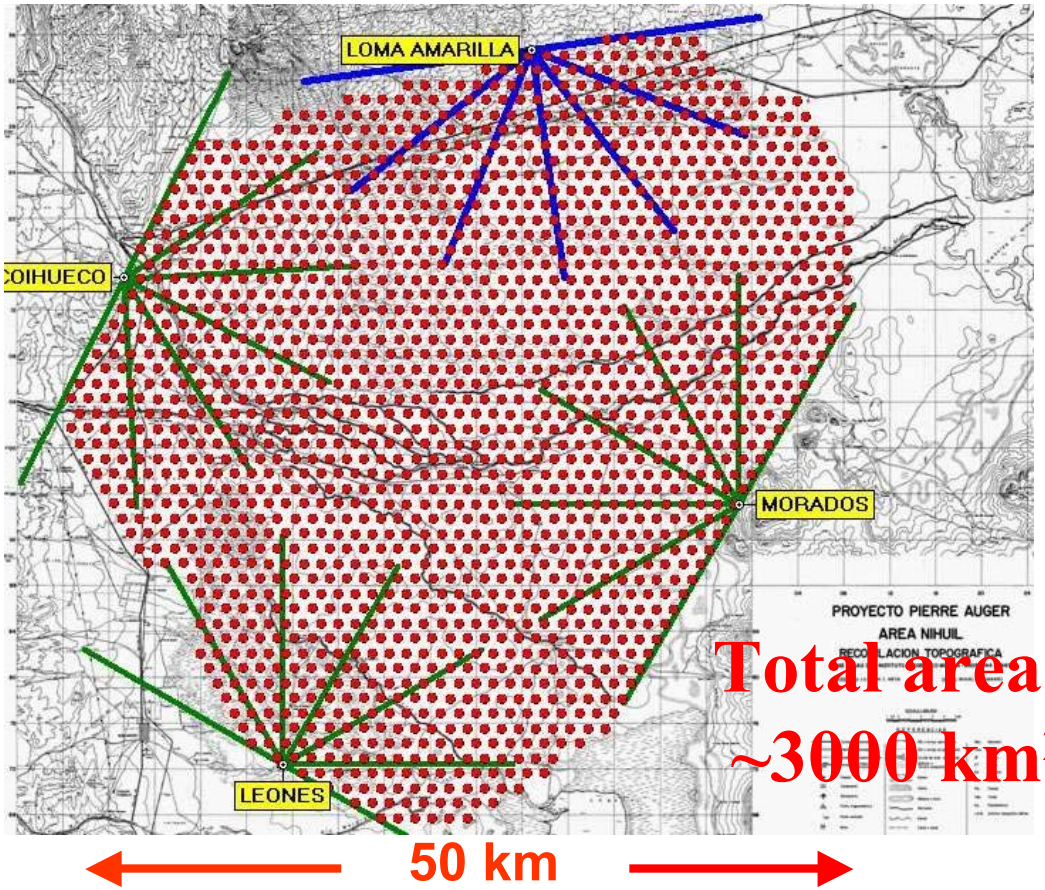


AUGER Observatory

Completed April 2008

Malargüe 35^0 S latitude

≈ 1400 m height ≈ 875 g/cm^2



- Very flat region with low population density
- Good atmospheric conditions (clouds,

1600 Surface detectors ("water tanks")
1.5 km spacing

24 fluorescence telescopes, 6 in each of the 4 sites + 3 higher elevation

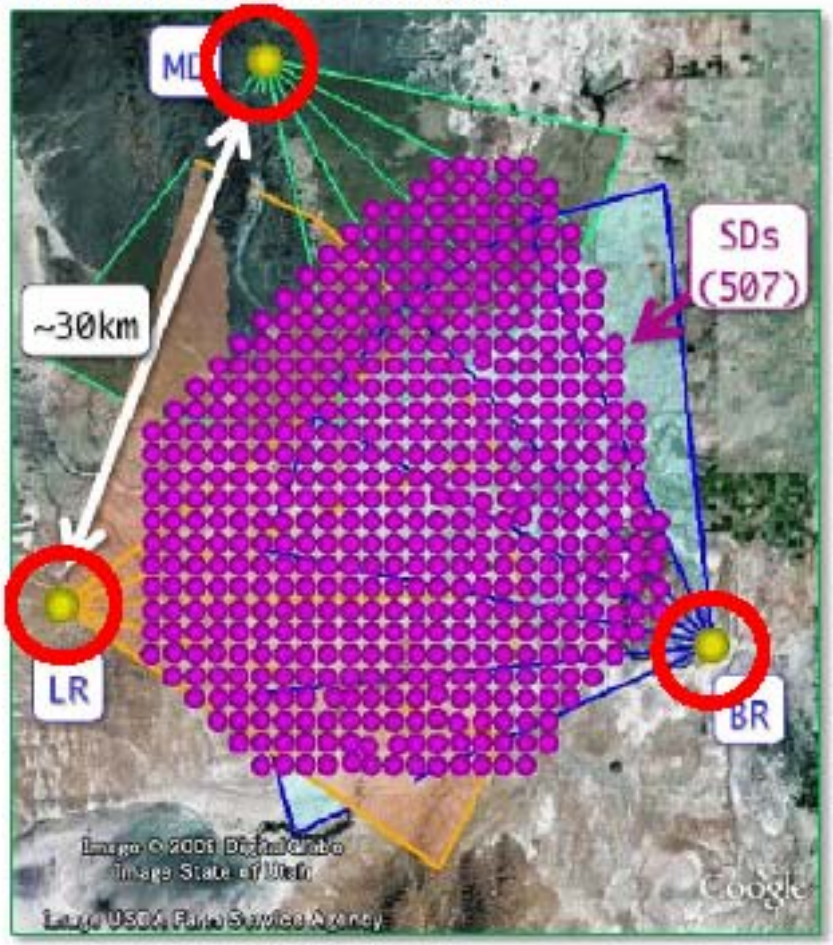
Fly's eye –> HiRes --> Telescope Array

TA detector

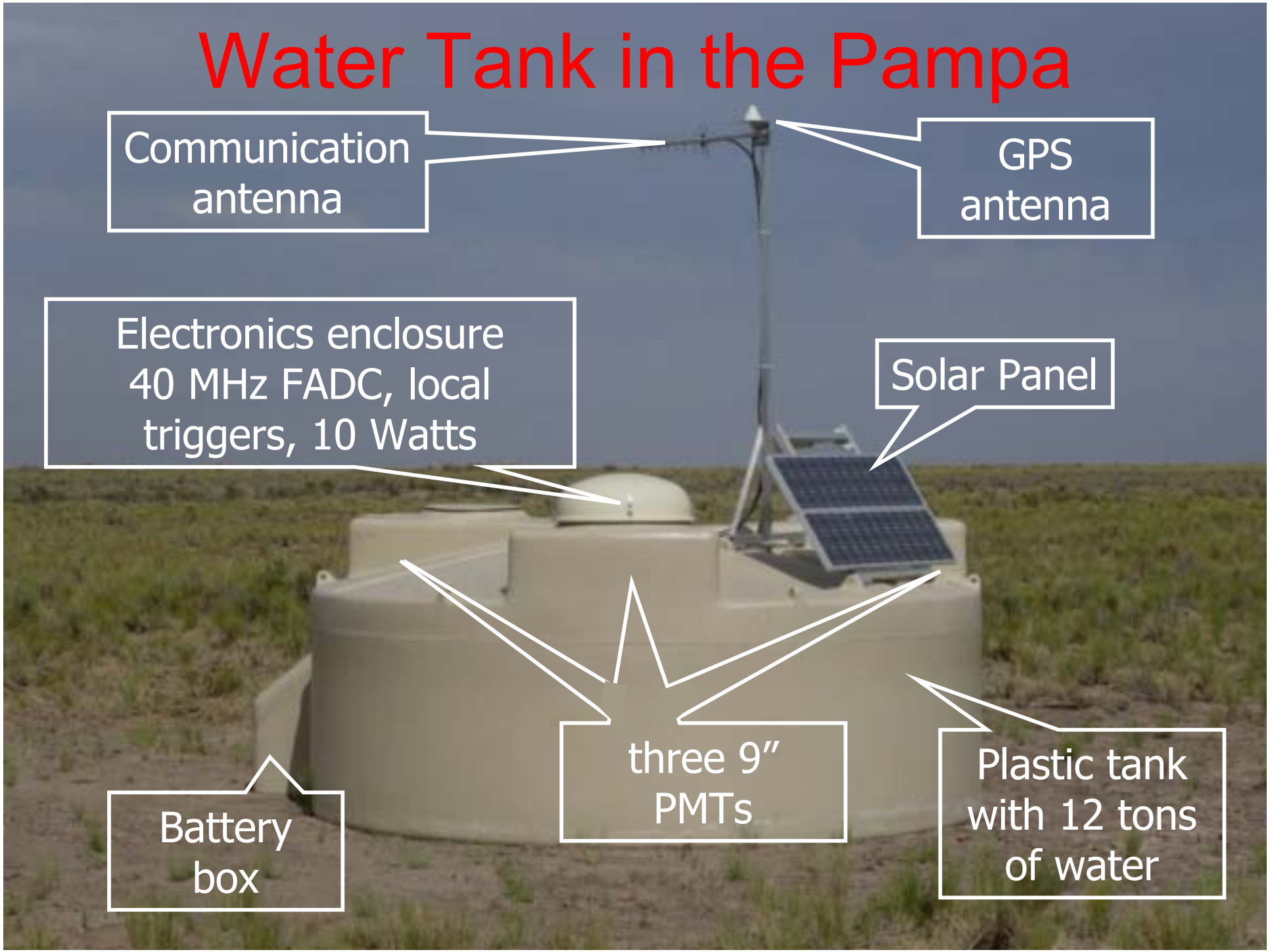
(¼ Auger)

- **Surface detector (SD)**
  - Plastic scintillator (a la AGASA)
  - 507 SDs
  - 1.2km spacing, 680km²
- **Fluorescence detector (FD)**
  - 3 stations (BR, LR, MD)
    - 38 telescopes (12+12+14) (a la HiRes)
- Location
  - Utah, USA
    - About 200km south to Salt Lake City
    - 39.3°N, 112.9°W
    - Altitude ~1400m

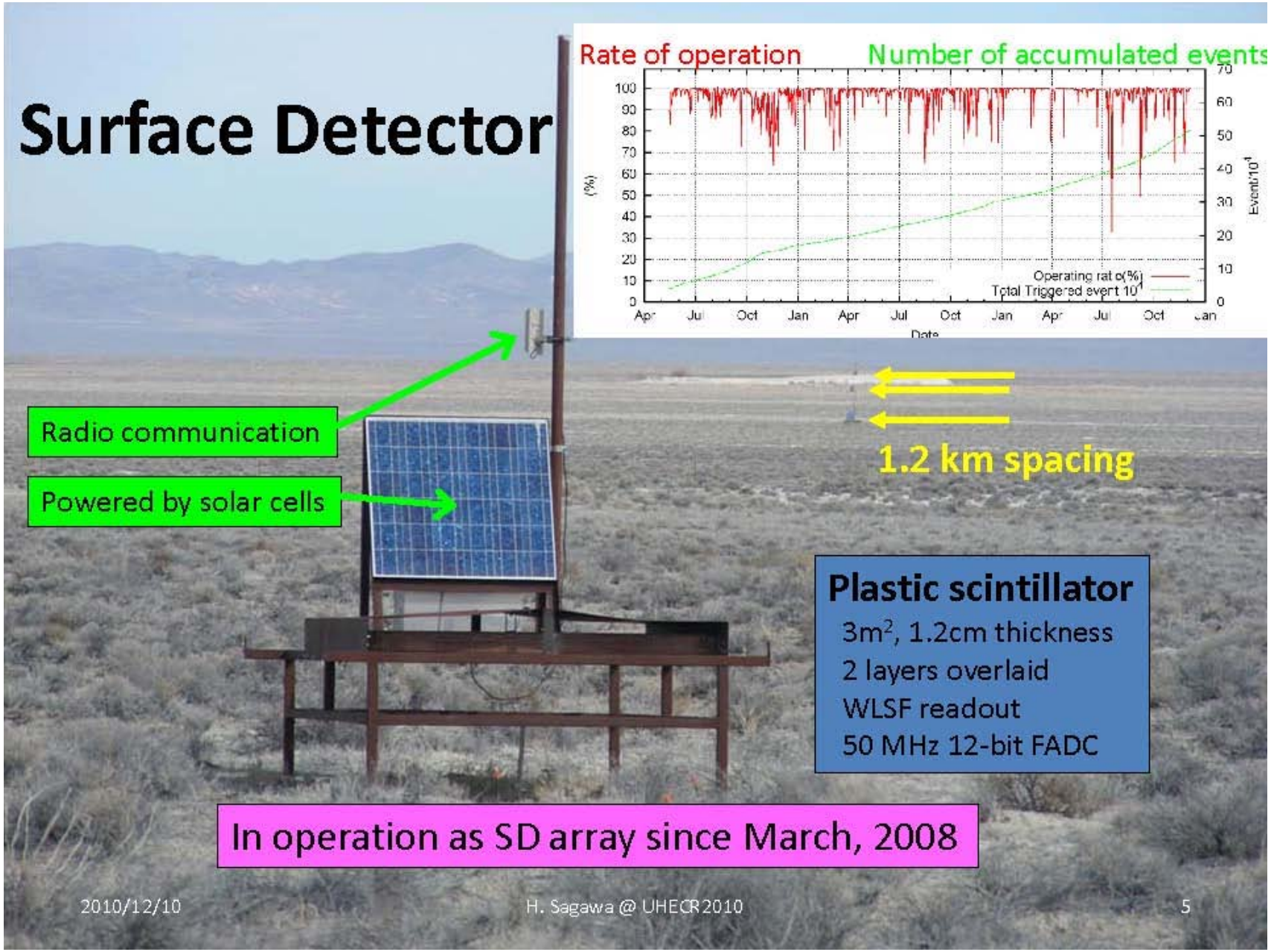
transfer HiRes telescopes



The largest detector in northern hemisphere

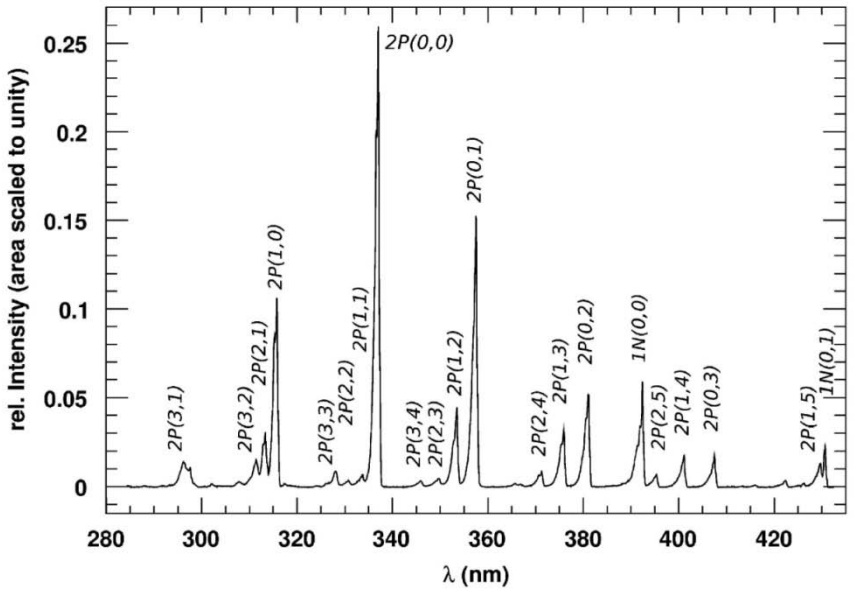

Water Tank in the Pampa
Communication antenna
GPS antenna
Electronics enclosure 40 MHz FADC, local triggers, 10 Watts
Solar Panel
three 9” PMTs
Battery box
Plastic tank with 12 tons of water

Surface Detector of Telescope Array



Emission spectrum

~ 300 – 450 nm

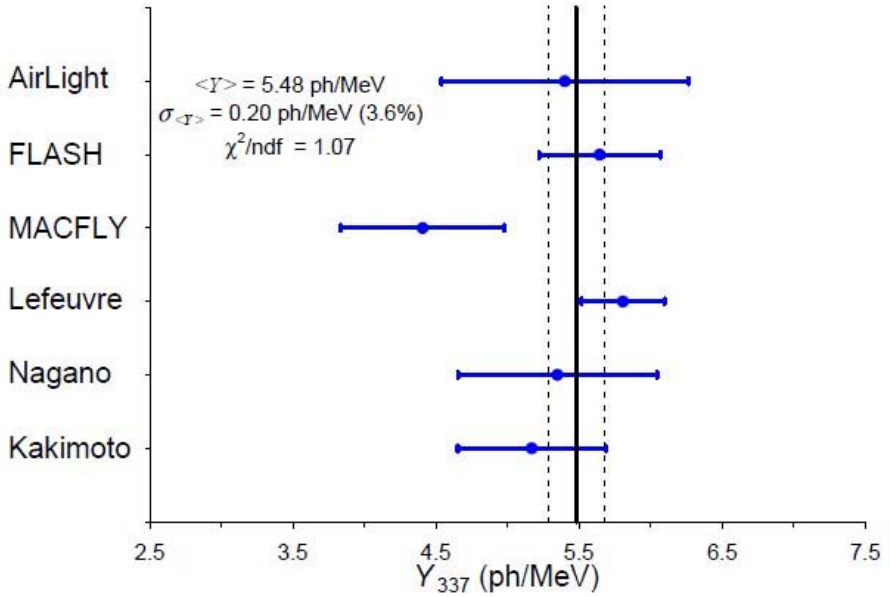


Fluorescence Yield

Number of photons per MeV deposited energy

Now known to better than ± 5 %

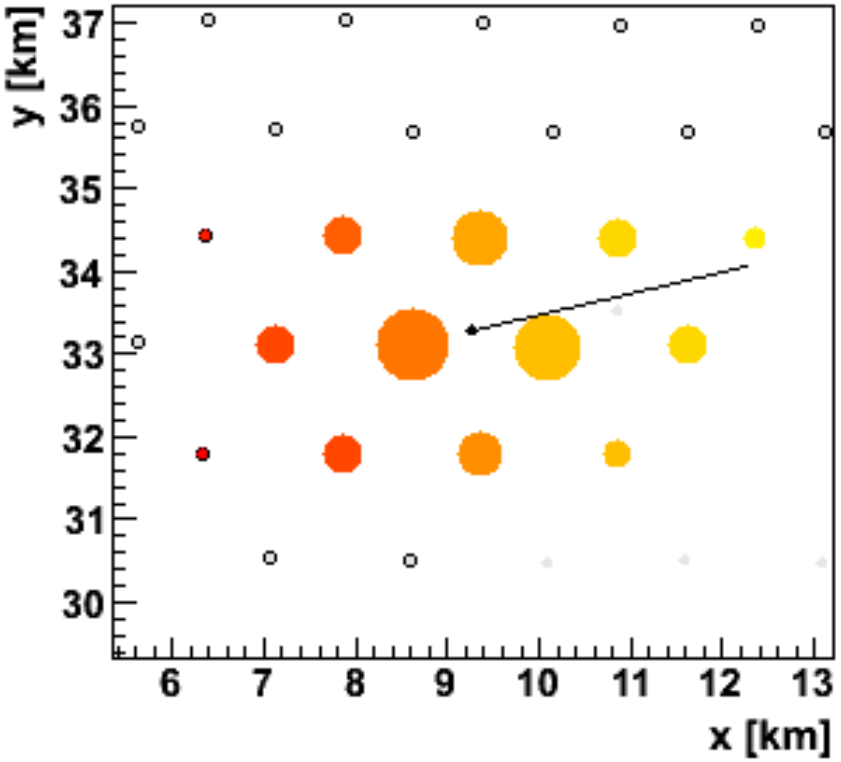
(F. Arqueros)

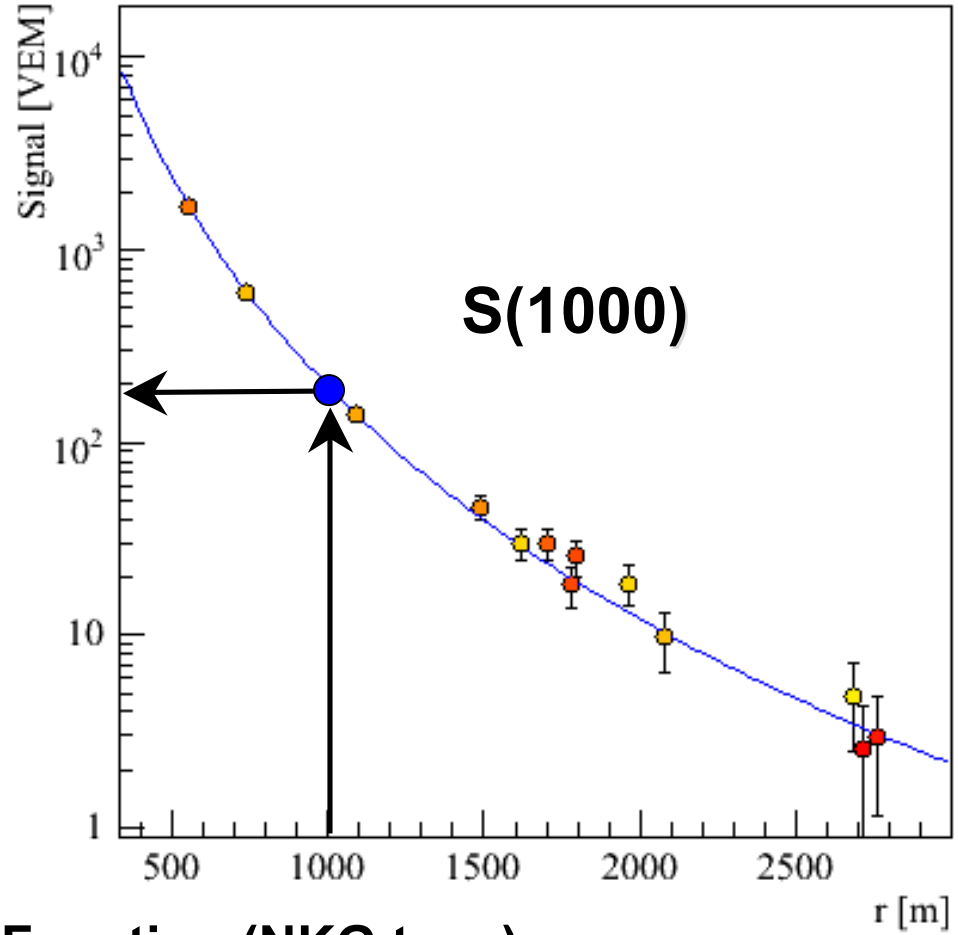


(b) Corrected Y_{337} values.

Energy Calibration
Auger / TA

Reconstruction of a SD event





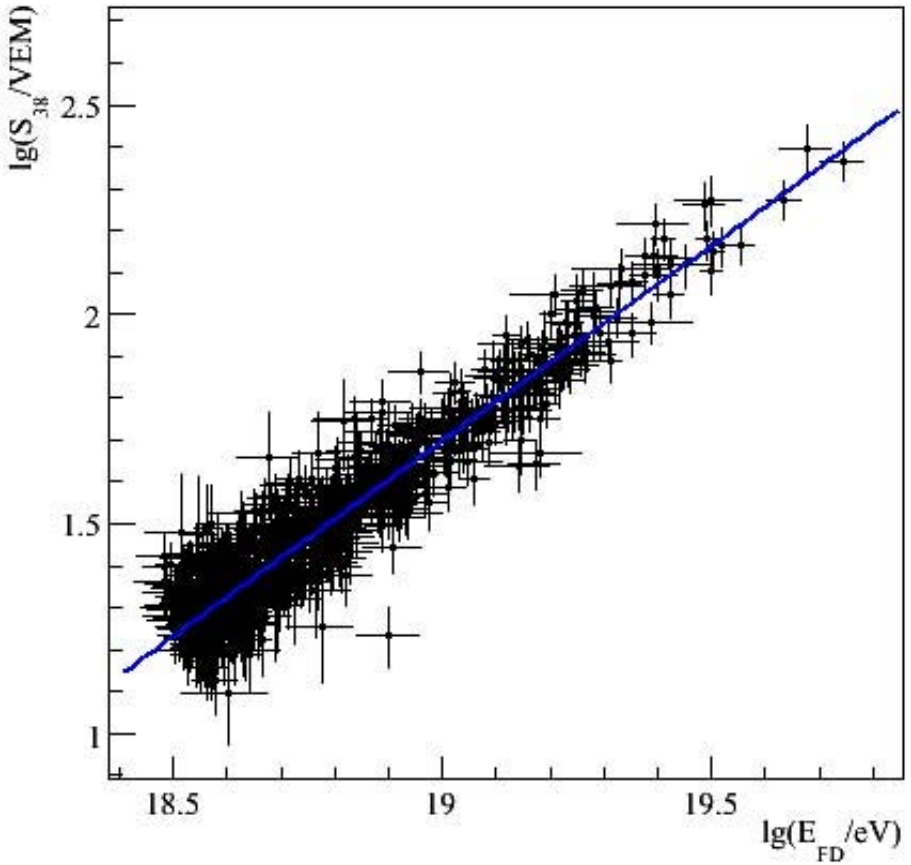
- Fit with Lateral Distribution Function (NKG type)
- Parameters determinated from fit: core position, S(1000)

S(1000) good energy estimator

Auger

Energy Calibration (SD+FD)

Independent of model calculations

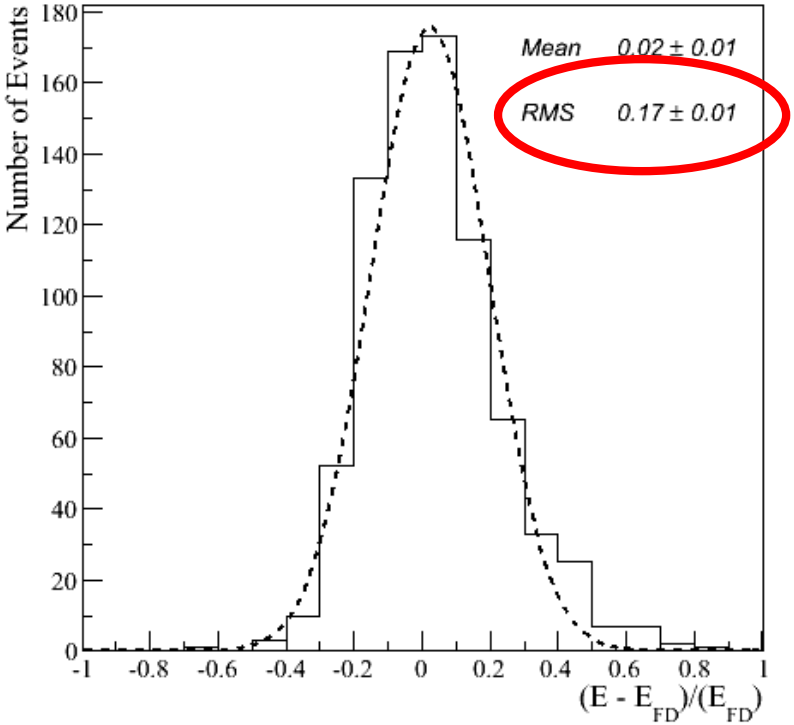


$$E = a \times (S_{38^\circ})^b$$

$$b = 1.07 \pm 0.04$$

795 high quality hybrid events

Energy resolution 17 %

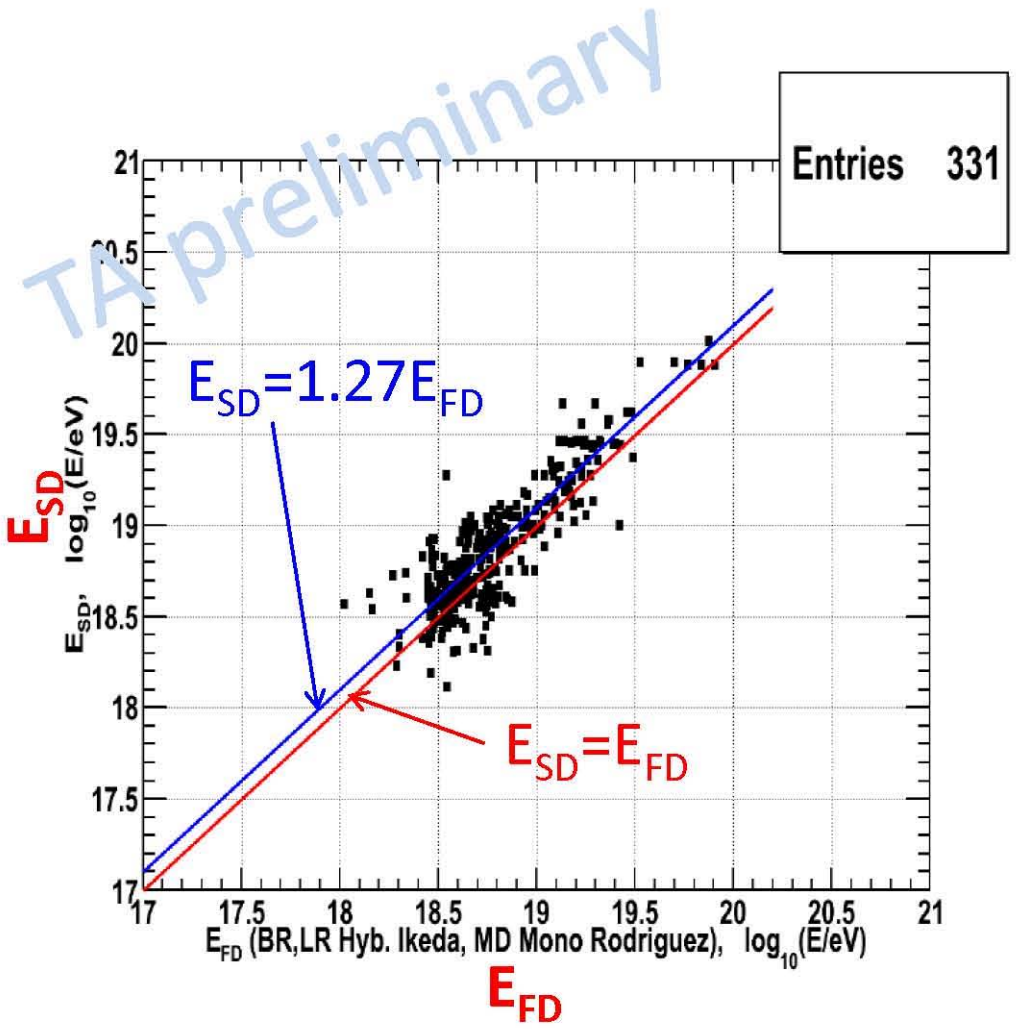


Auger : Uncertainy on FD energy scale

Source	$\Delta E_{FD}/E_{FD}$(%)
Absolute Fluorescence Yield	14
FD absolute calibration	10
Atmospheric Attenuation Aerosol etc.	8
FD reconstruction method	10
Invisible energy	2
TOTAL SYSTEMATIC	**~ 22**

Now reduced to 12 – 15 % (ICRC 2011)

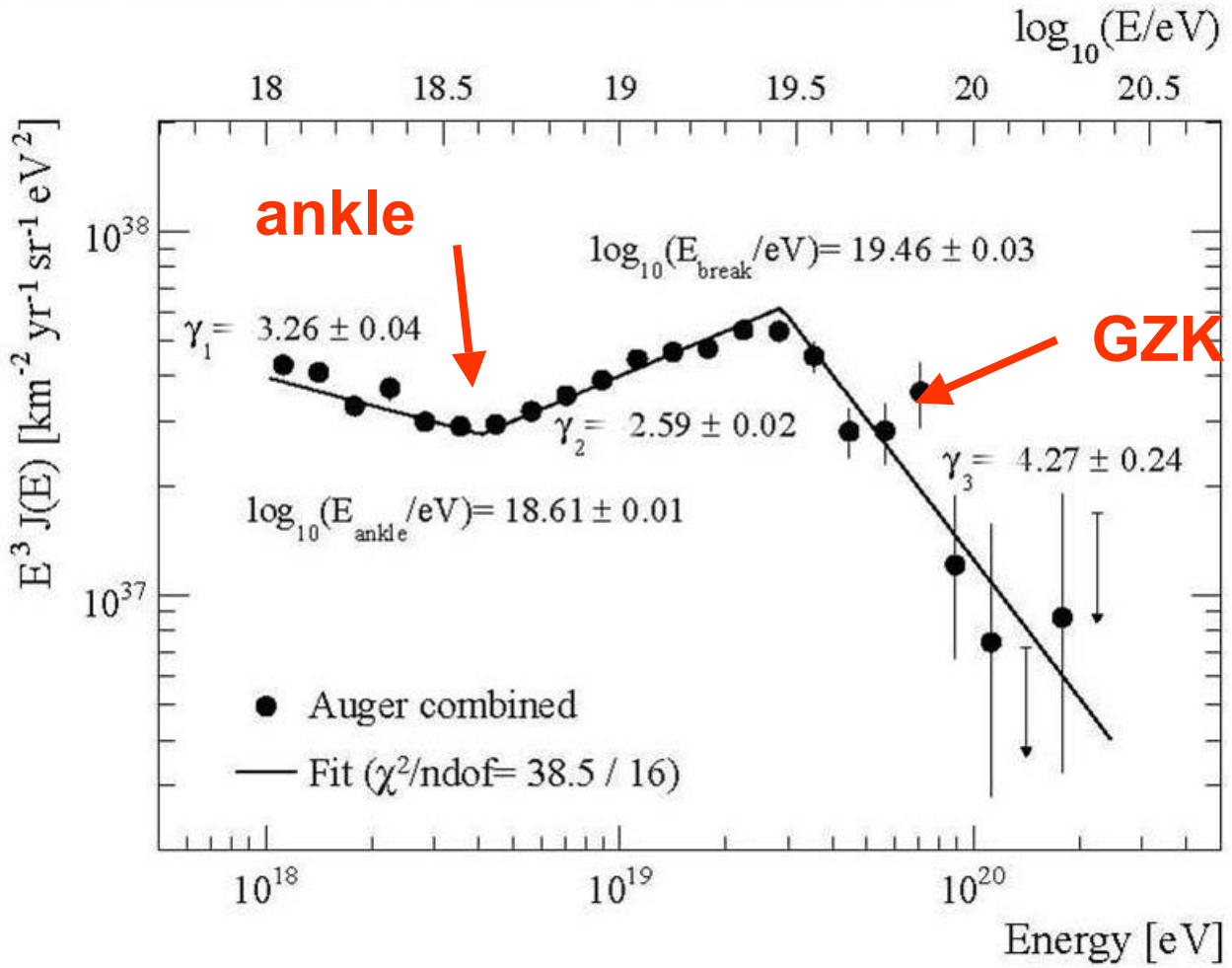
Comparison of E_{SD} and E_{FD}



- Energy scale is determined experimentally by FD without referring to MC.
- Set SD energy scale to FD energy scale using well-reconstructed events detected by both detectors.
- 27% renormalization.
  - Systematic error 19%
    (from systematic error of energy by hybrid analysis)

Energy Spectrum

Auger Fits power spectrum $E^{-\gamma}$



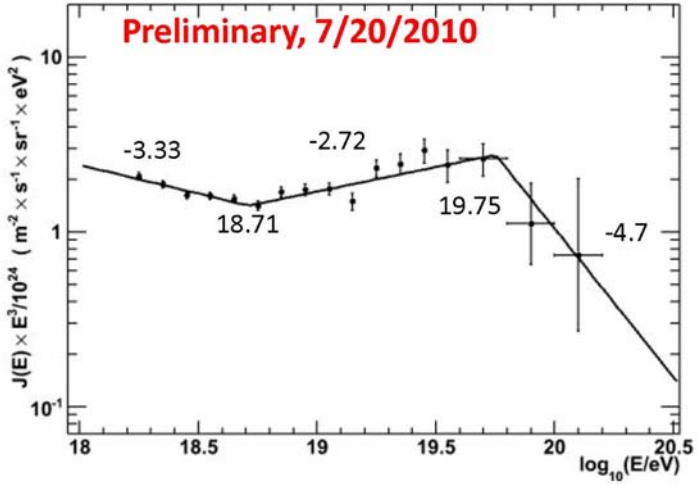
Confirmation of Greisen – Zatsepin – Kuz'min prediction: interaction with the CMB

- GZK cut from pion photoproduction
- Ankle from e^+e^- production (Berezinski and Grigorieva)

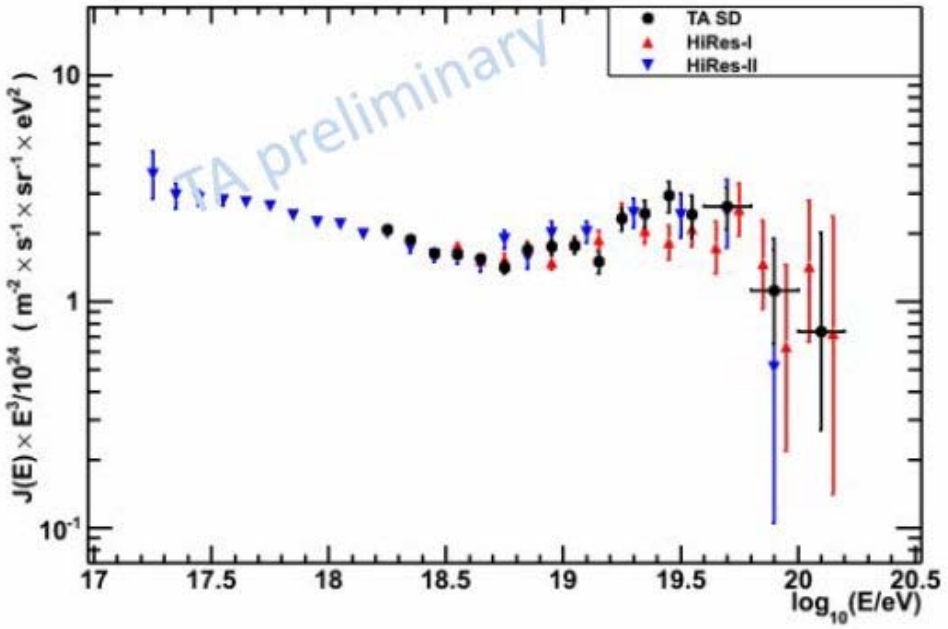
Features already observed by HiRes

TA SD Spectrum

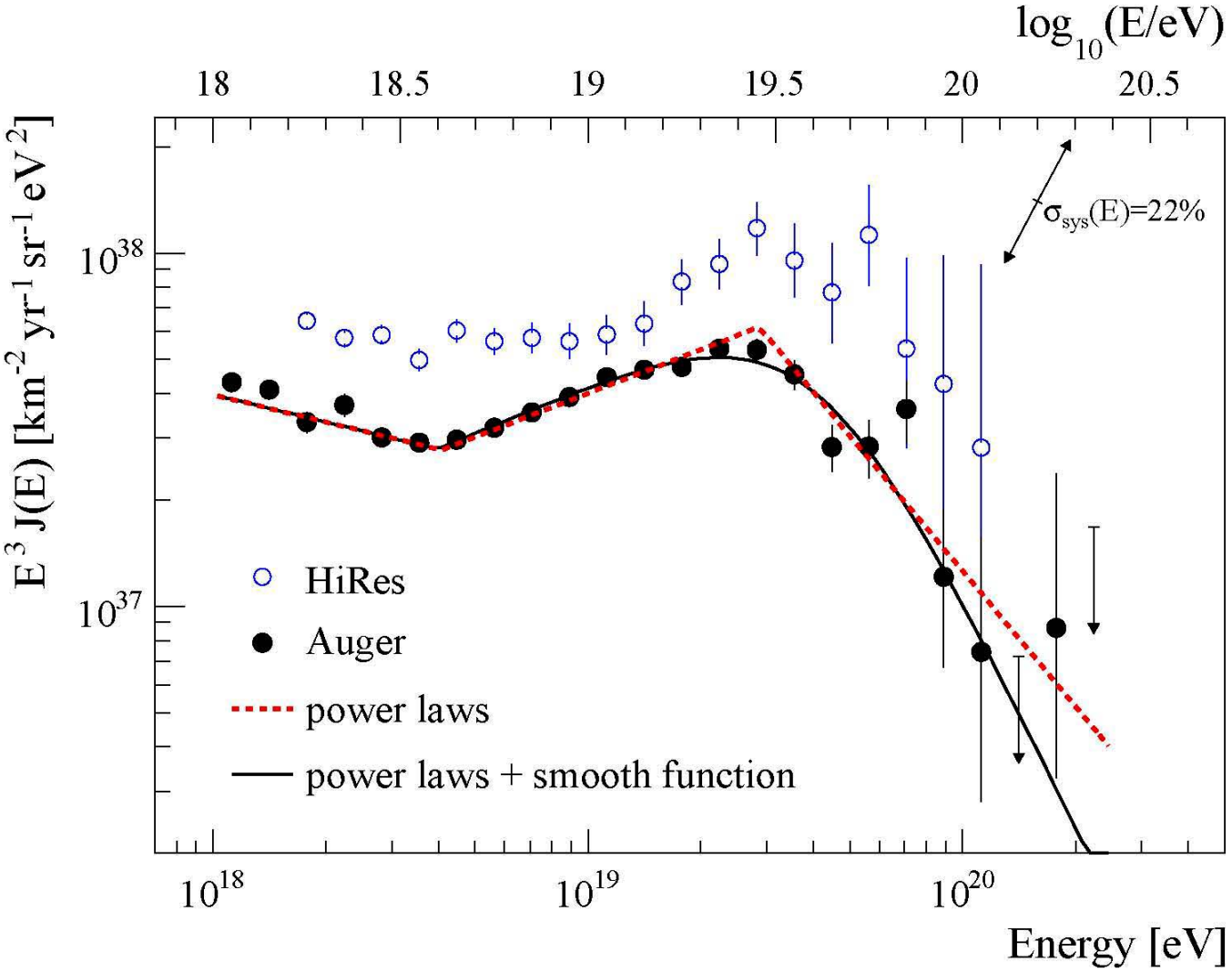
TA SD energy is rescaled to FD energy.



TA SD and HiRes Spectra



About 20 % energy scale difference !



HiRes/ TA – Auger observe the GZK suppression

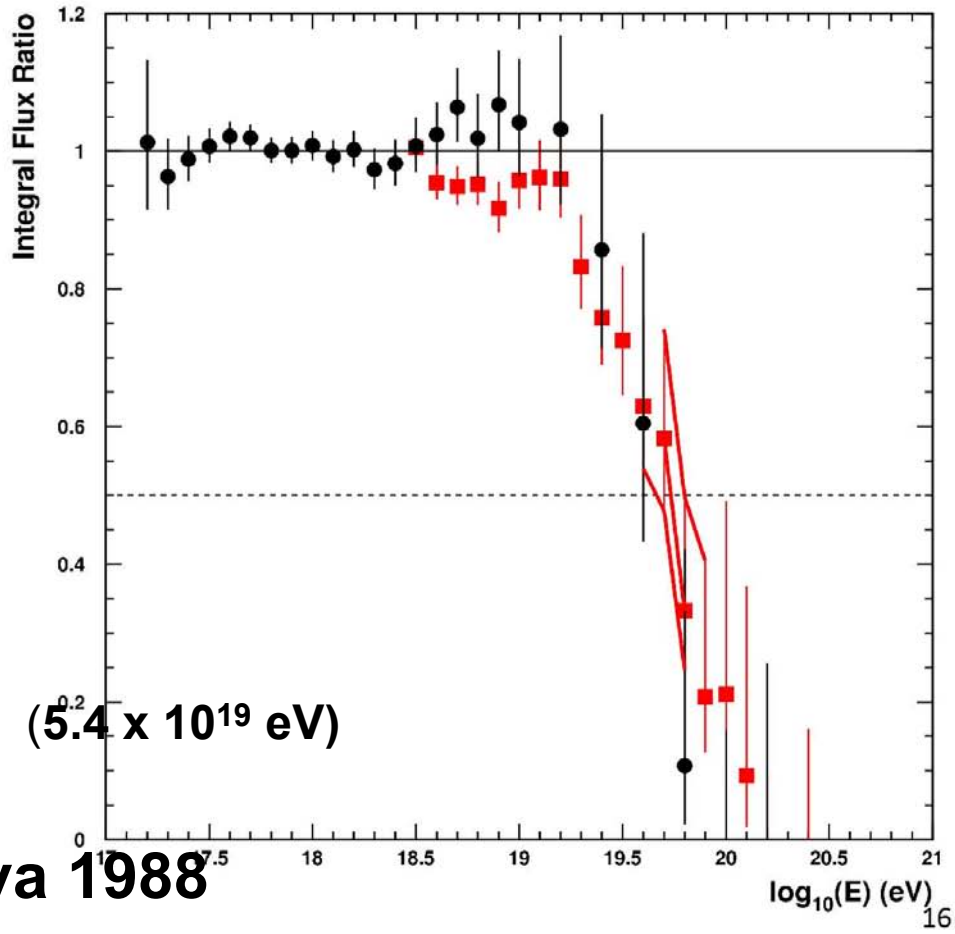
But : problem on the energy scale

HiRes integral spectrum

Berezinsky $E_{1/2}$ Test

- $E_{1/2}$ is the energy where the integral spectrum falls below ½ × power-law extension.
- Berezinsky *et al.*: $\log_{10}E_{1/2} = 19.72$, for a wide range of spectral slopes.
- Use 2 Break Point Fit with Extension for the comparison.

$\log_{10}E_{1/2} = 19.73 \pm 0.07$



(5.4 x 10^{19} eV)

Berezinsky, Grigorieva 1988

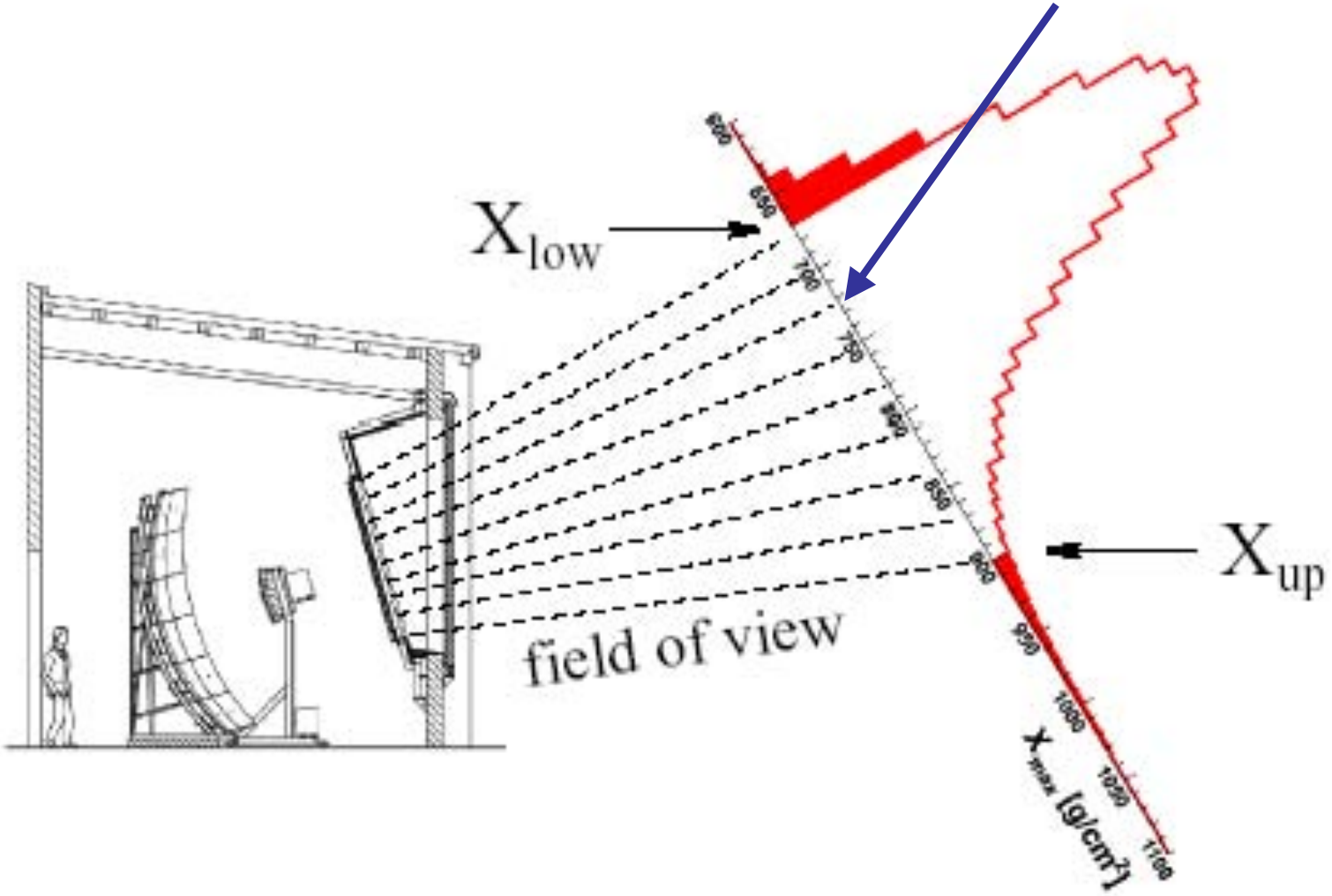
HiRes, Dec 2010

Log $_{10}$ $E_{1/2}$ = 19.76

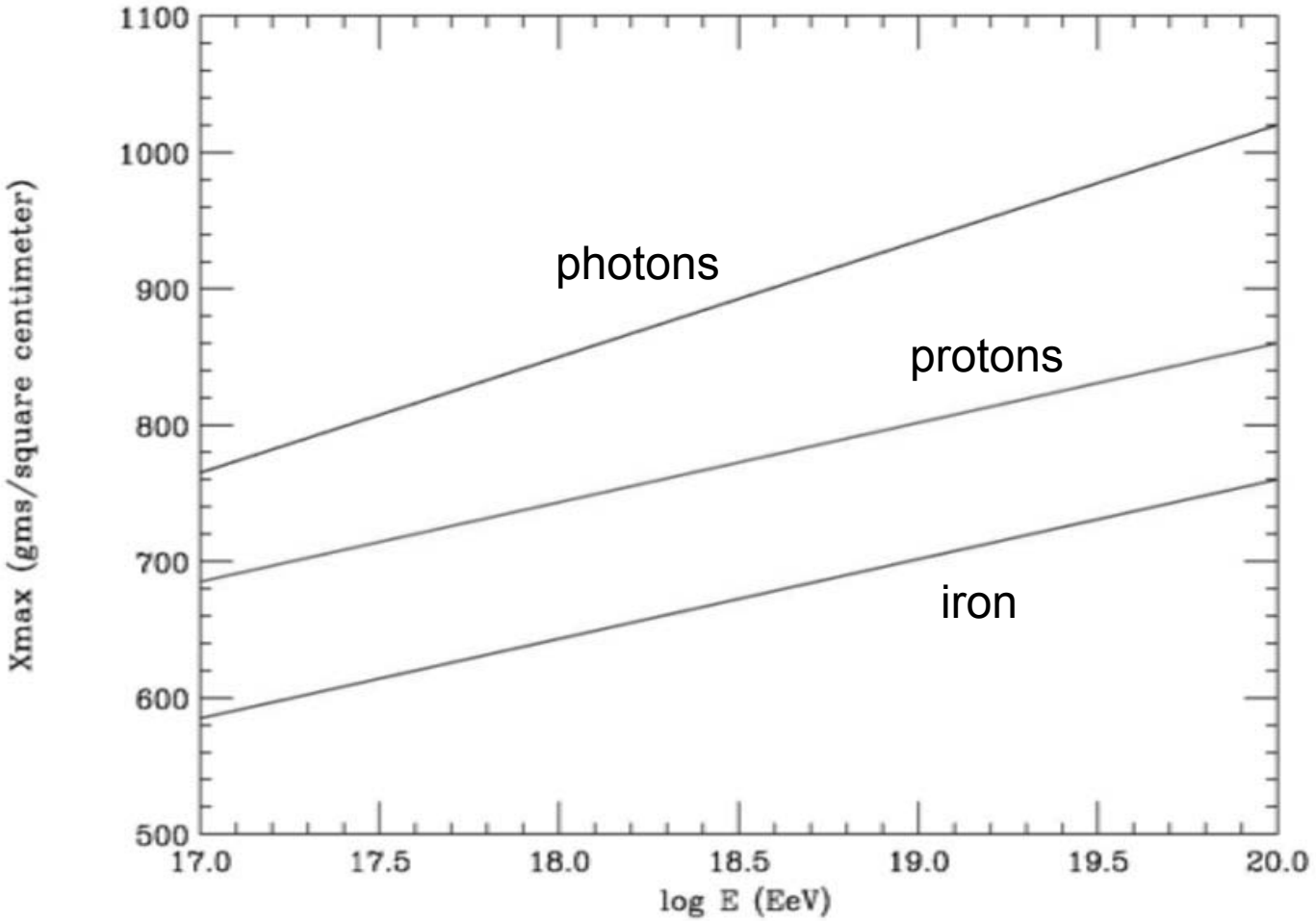
Mass composition

Study of composition – mass of the primaries

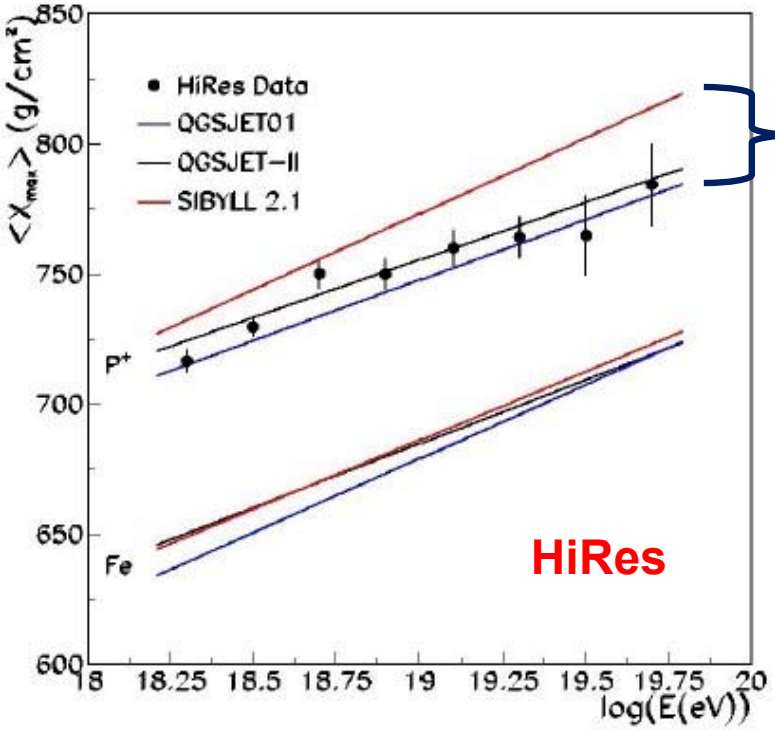
Depth of the maximum X_{max}



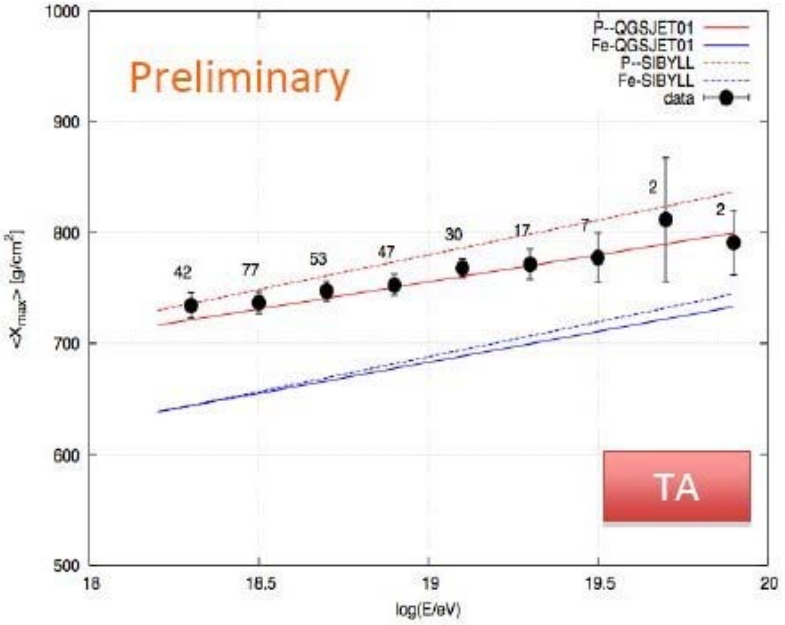
$< X_{max} >$ for different primaries (photons, protons and iron nuclei)

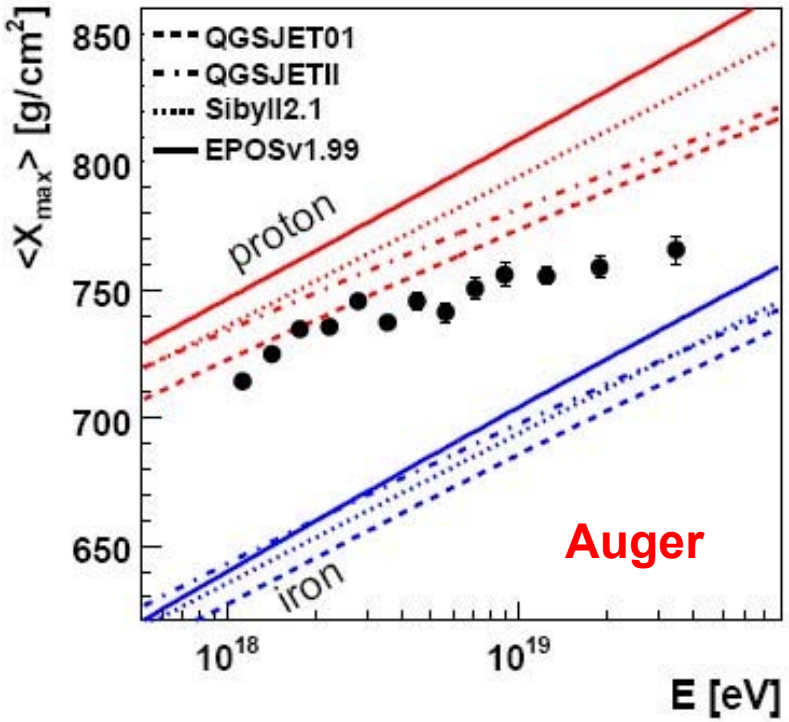


Xmax



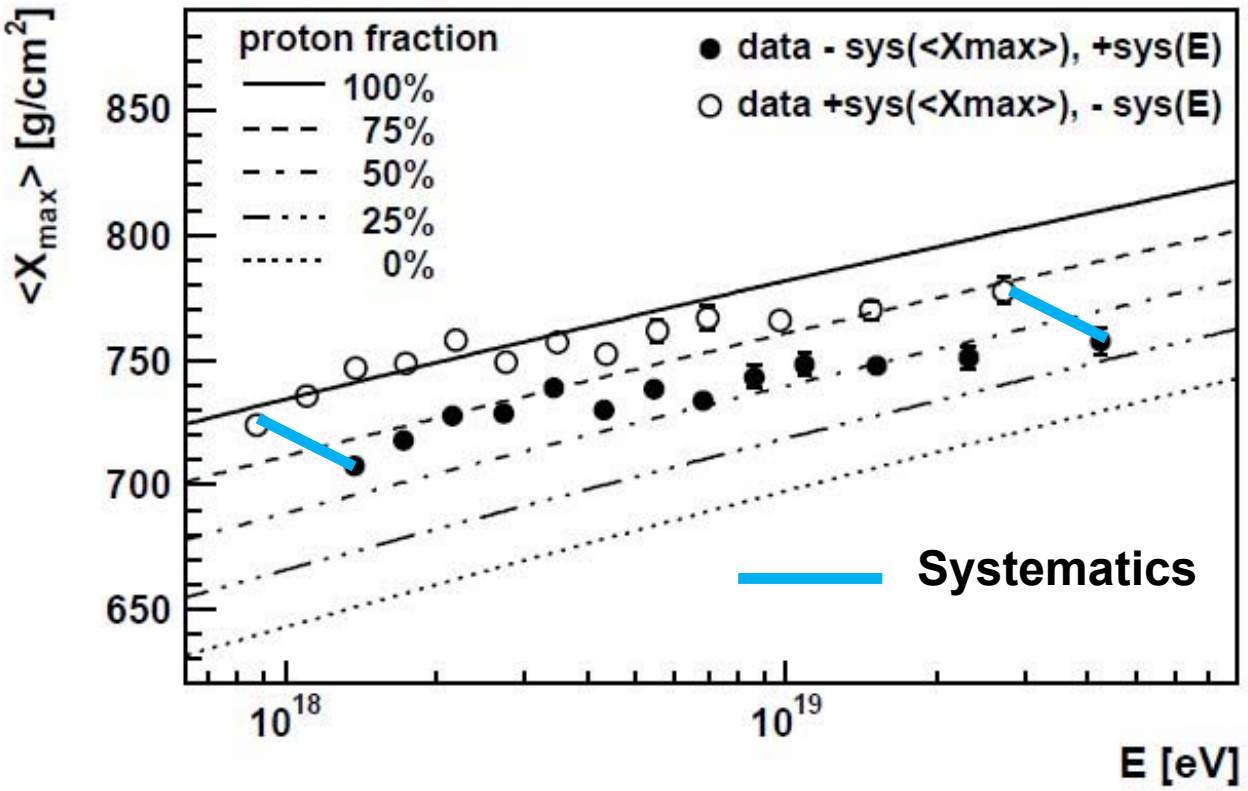
Model dependence !





Auger - Xmax

QGSJET II



Provisional conclusions:

- Model dependence too large
- In the ankle region protons or mainly protons (ankle as effect of e+e- production)
- Above ~10^{19} eV, disagreement HiRes/TA vs. Auger. Indication mixed composition ?

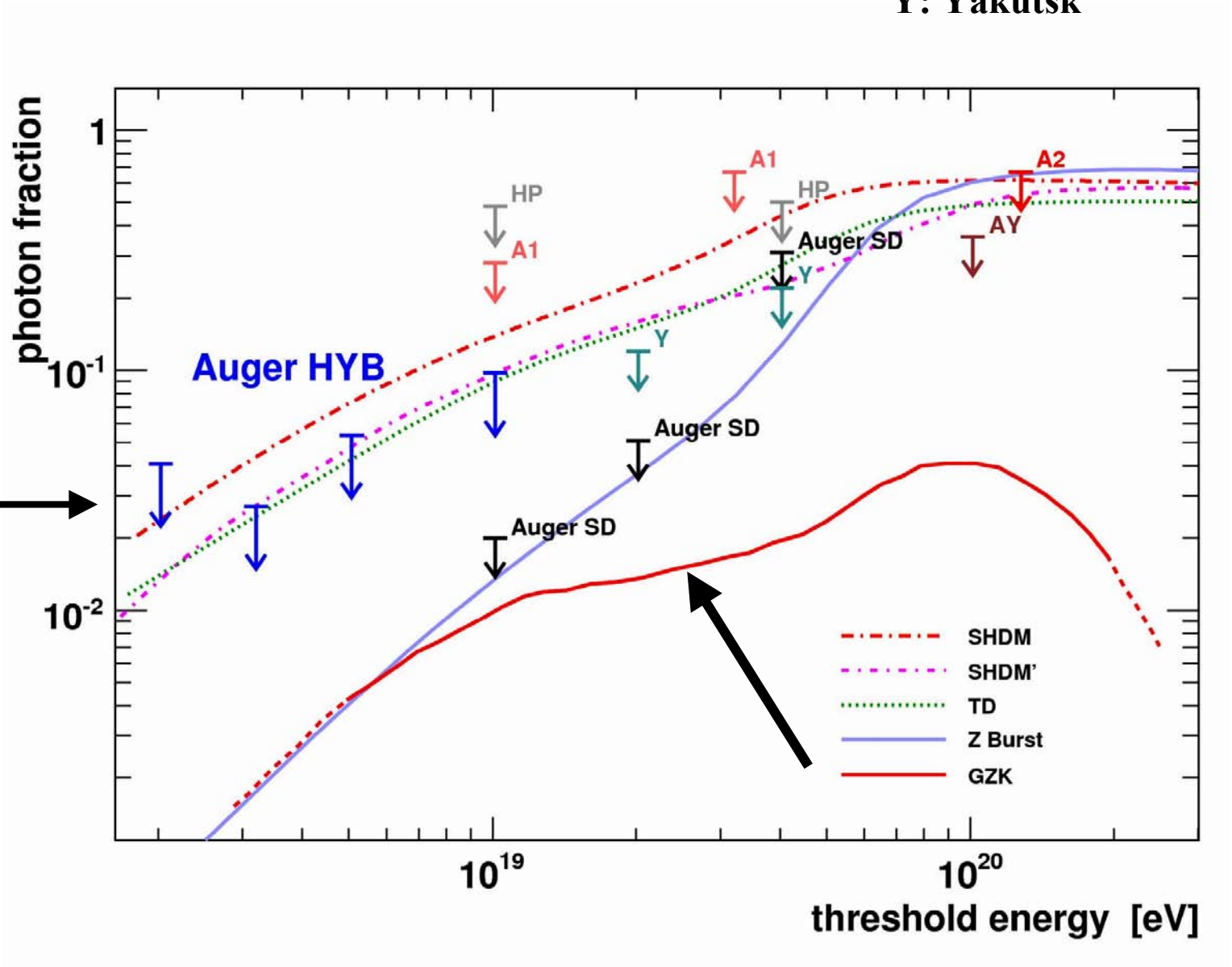
  Study to reduce systematic uncertainty going on.

Photon search

Limits on photon fraction

Expect photons from GZK: $p + \gamma \rightarrow p + \pi^0$

HP: Haverah Park
A1,A2: AGASA
Y: Yakutsk



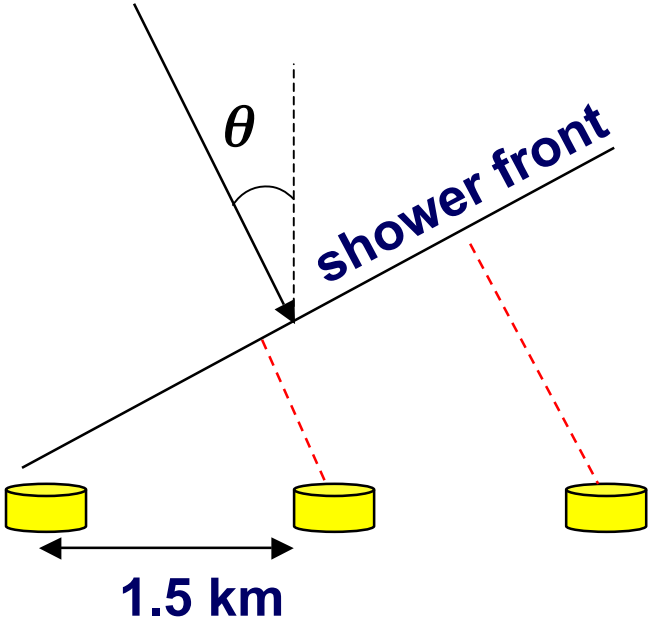
~ 3 %

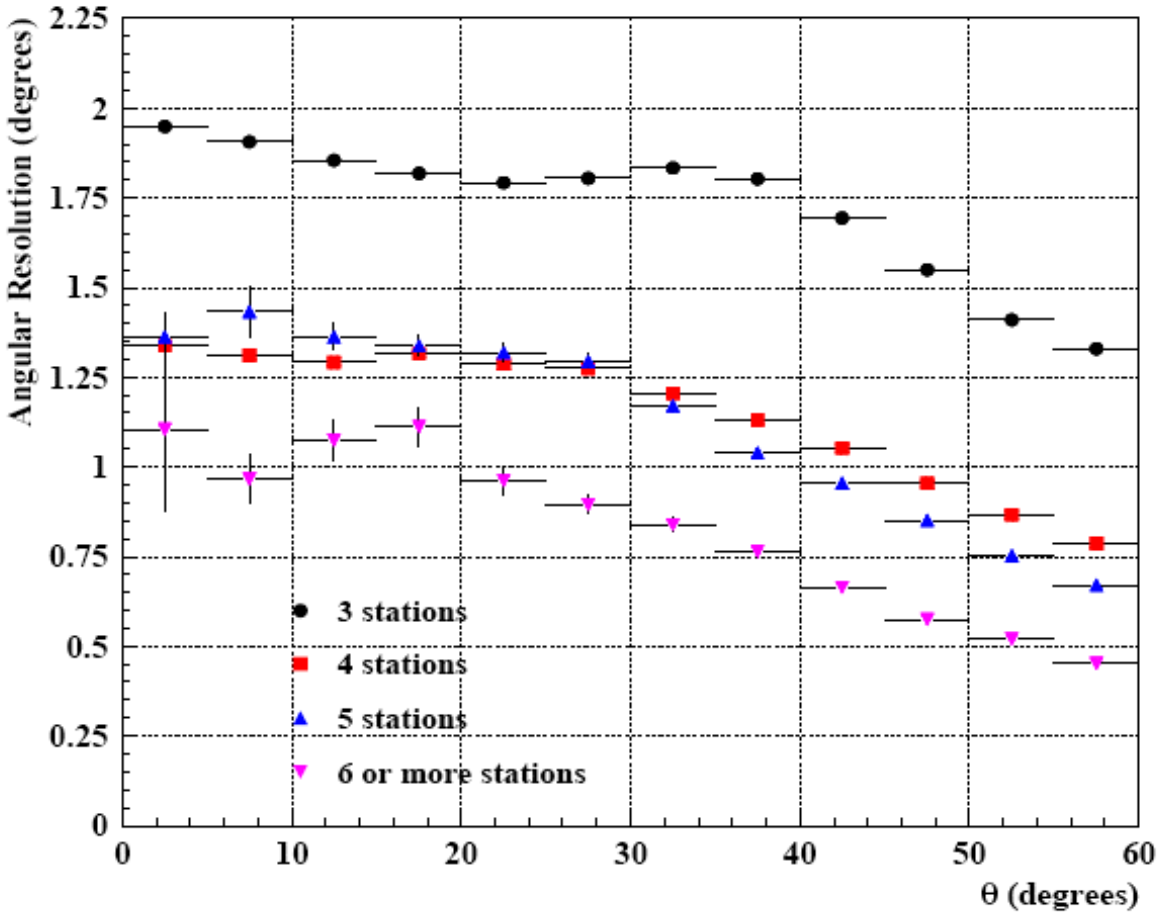
Super Heavy Dark Matter

Relic of "topological defects"

Correlation extragalactic objects

SHOWER DIRECTION from surface array (Auger)





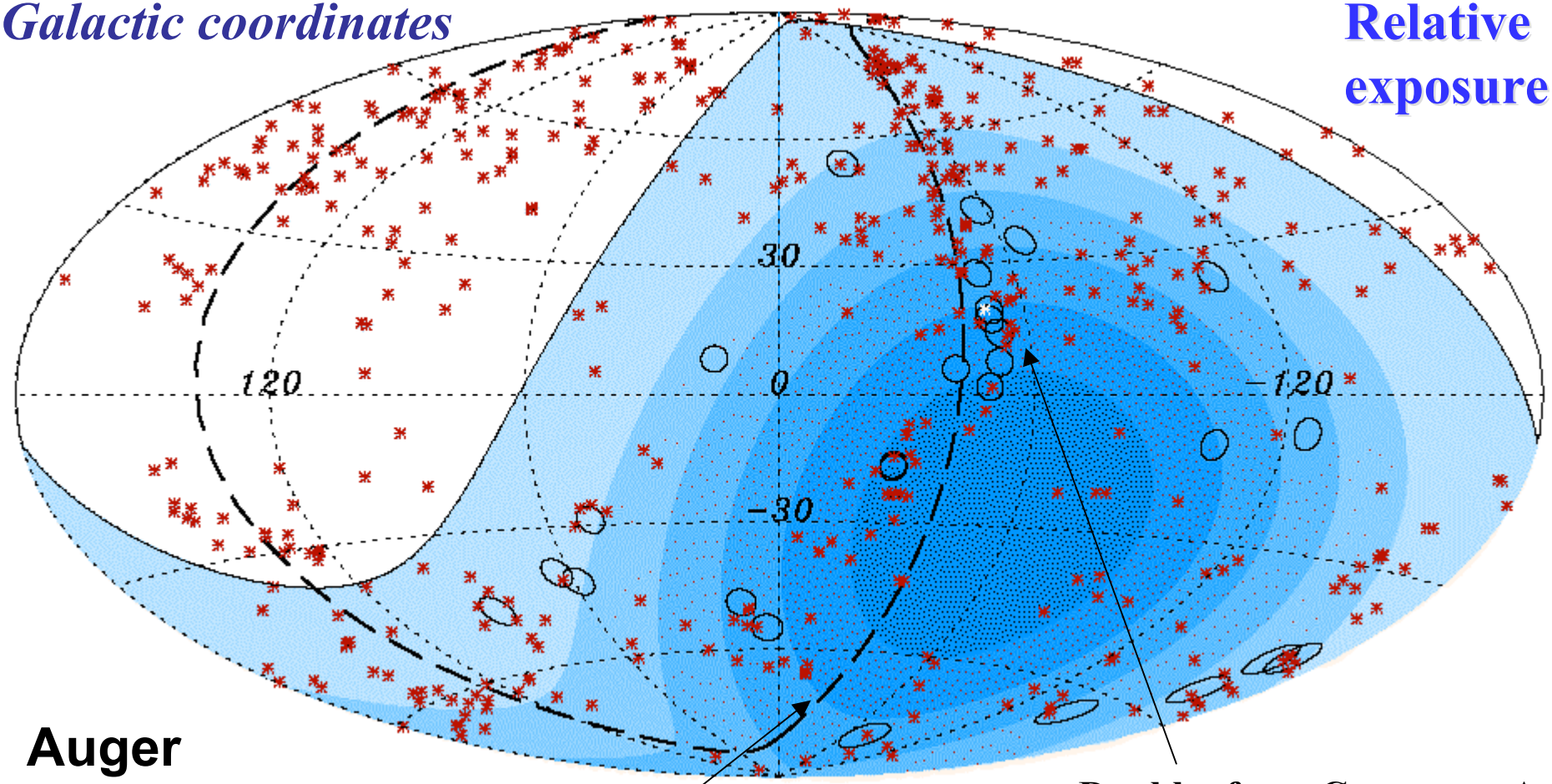
Fit of the particle arrival times with a model for the shower front (plane → paraboloid)

very good time resolution (~ 12 ns)

Vertical shower of energy 10^{19} eV activates 7-8 stations

Véron &Véron-Cetty catalogue
442 AGN (292 in f.o.v.)
z<0.018 (75 Mpc)

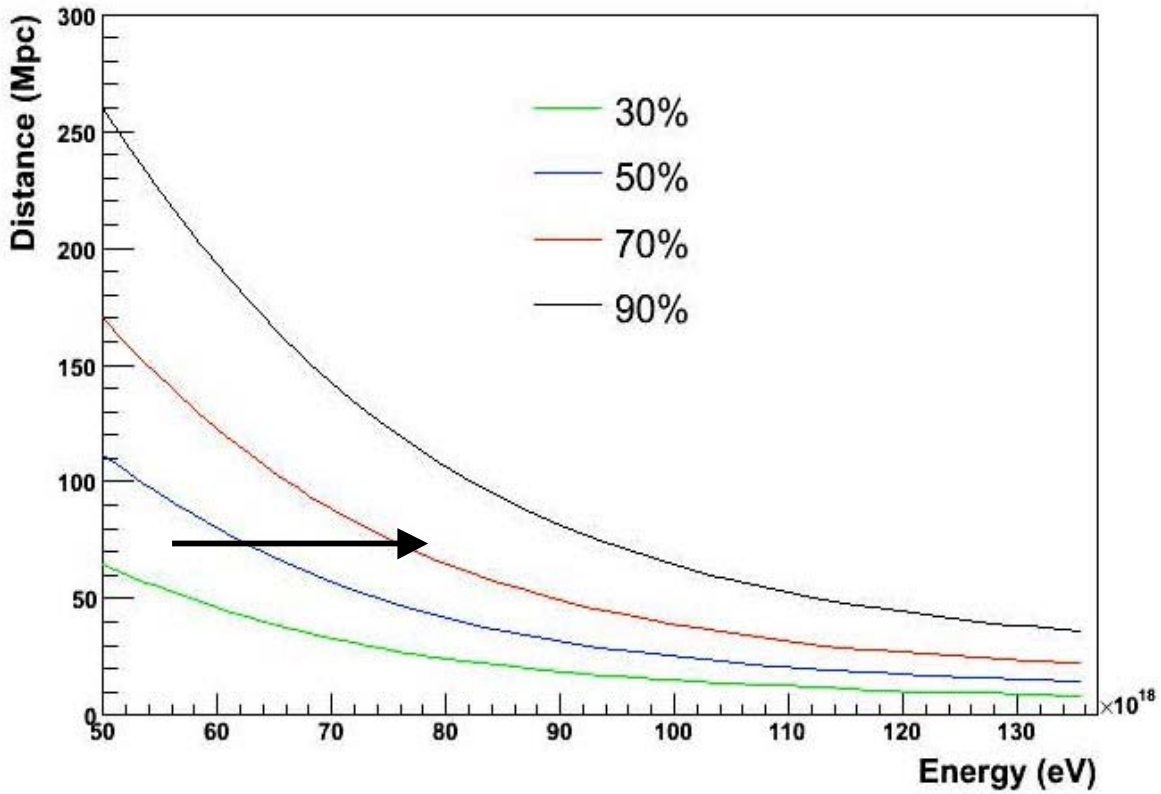
27 events E > 55 EeV
18 events correlate with
AGN within 3.1^0



Auger
Science paper
August 2007

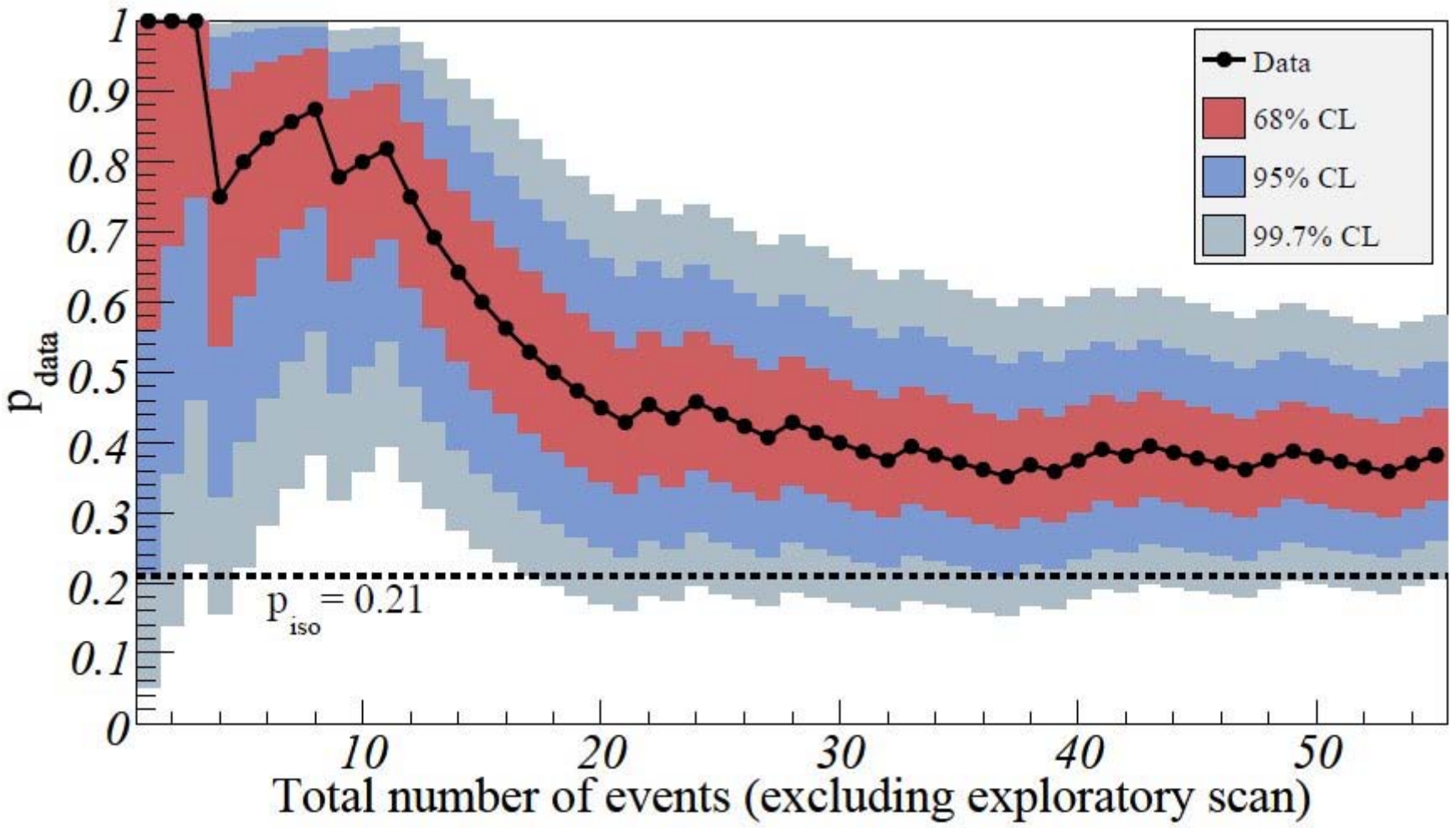
GZK Horizon – GZK sphere:

maximum distance of the sources for protons arriving at the Earth with energy above a given value



Energy (EeV)

Correlation with VCV AGN - Updated

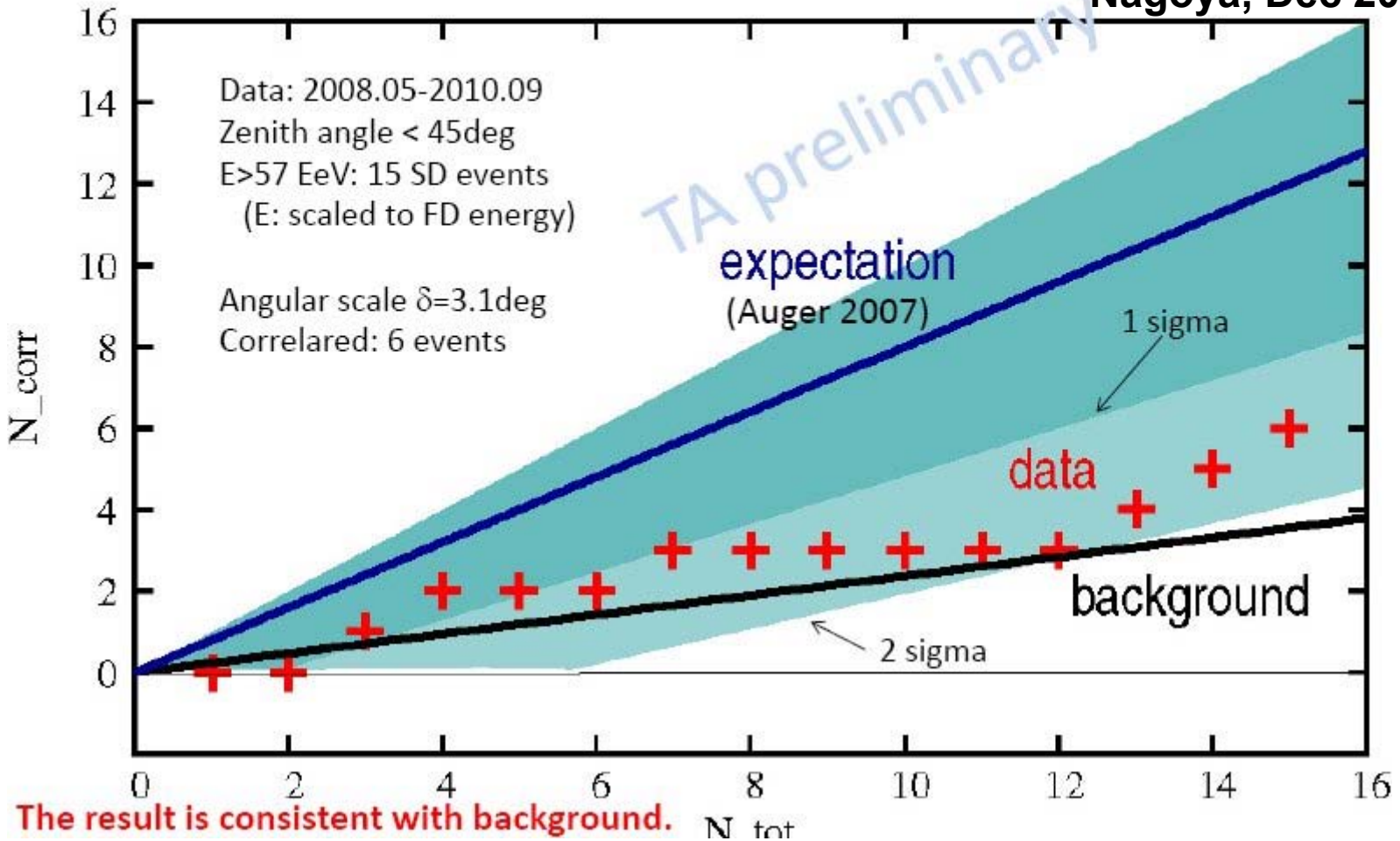


At present HiRes – TA don't see a correlation (lower statistics, North vs. South)

Correlation with AGN

(talk by P.Tinyakov)

Nagoya, Dec 2010



The result is consistent with background.

Auger - Study of correlations with respect to other catalogs of galaxies. Select galaxies within 200 Mpc (GZK sphere)

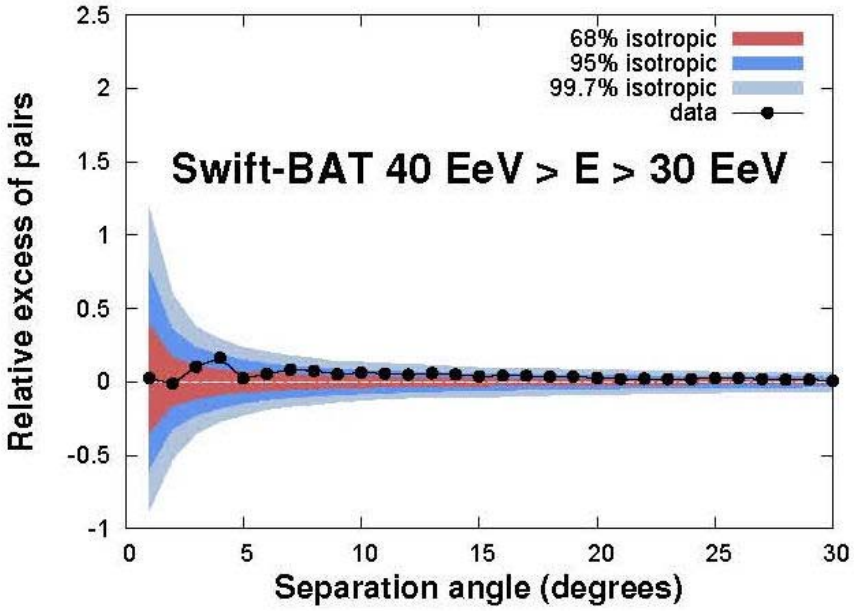
- AGN from Swift – BAT catalog.
  All sky hard X-ray survey. (373 objects)

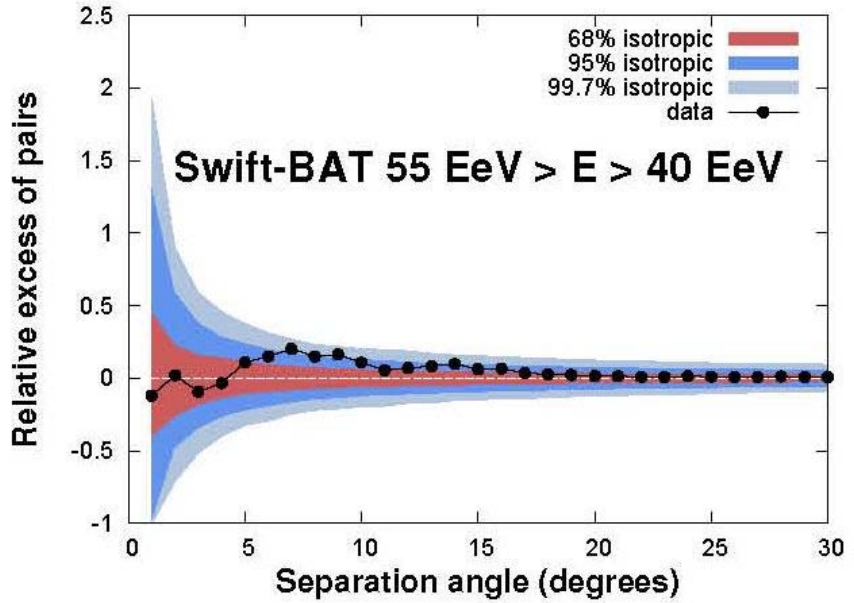
Procedure: the arrival direction of each event forms a pair with every object in the catalog. The separation angle is ψ. We calculate the number of pairs $N_p(\psi)$ with separation less than ψ.

Relative excess with respect to isotropic expectations of pairs having angular separation less than any given angle ψ :

$$N_p(\psi) \; / \, N_p(\psi)_{iso} \; - 1$$

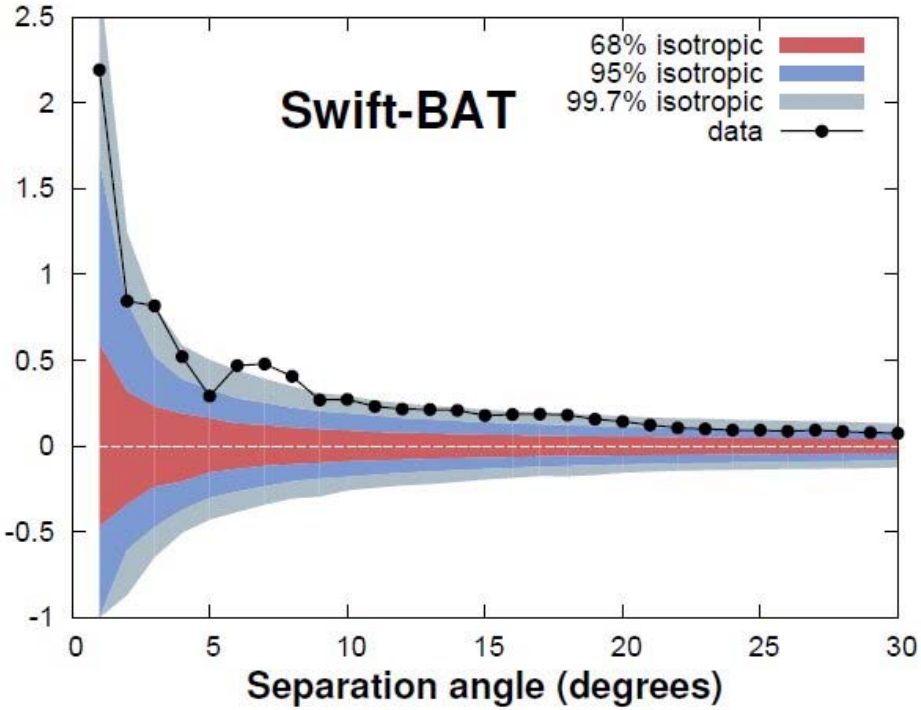
• Auger AGN from Swift – BAT catalog. (373 objects)

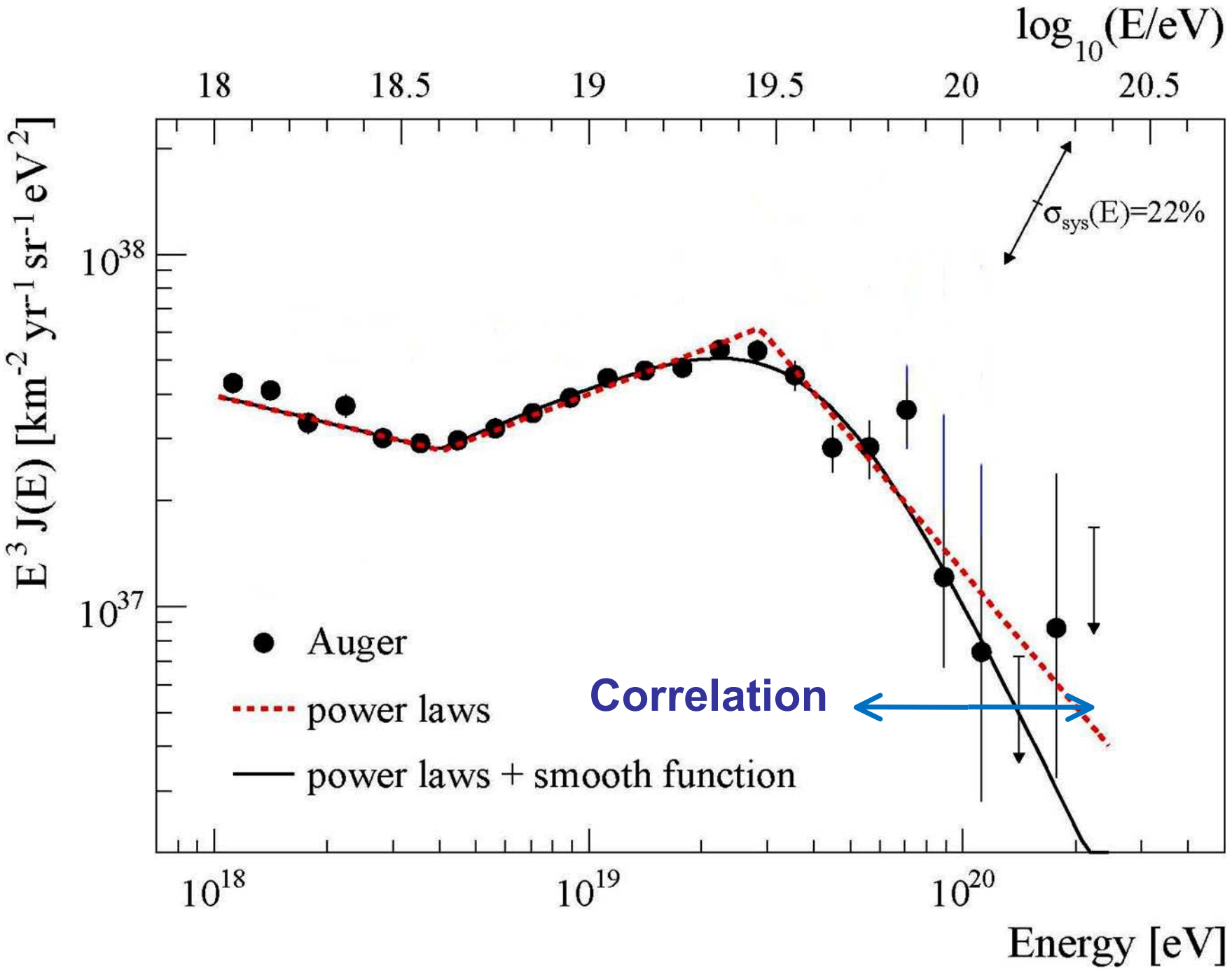




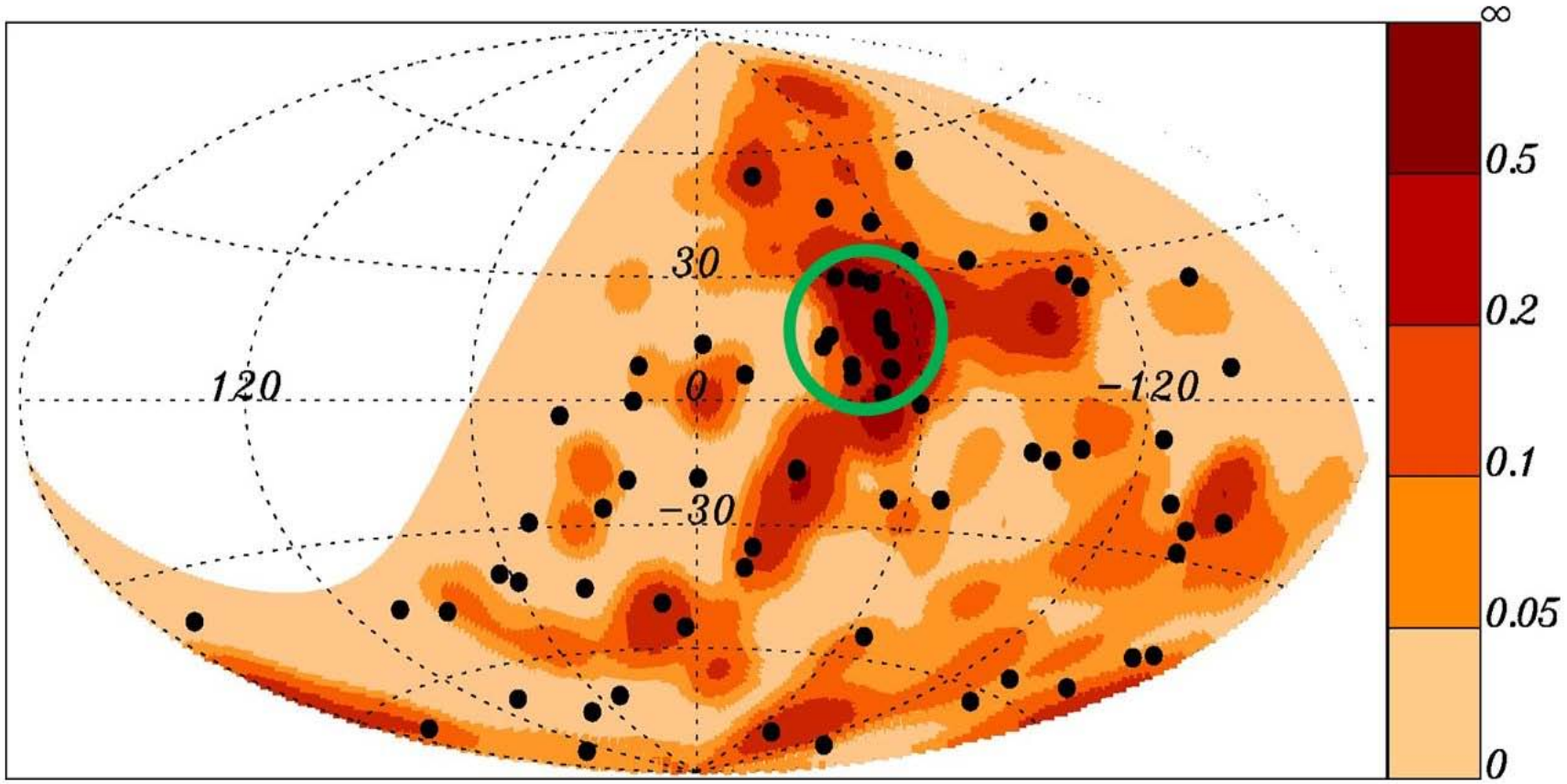
Evolution of the correlation with energy

E > 55 EeV




log10(E/eV)
18
18.5
19
19.5
20
20.5
σsys(E)=22%
E3 J(E) [km-2 yr-1 sr-1 eV2]
10^38
10^37
Auger
power laws
power laws + smooth function
Correlation
10^18
10^19
10^20
Energy [eV]

Auger. **Events for E > 55 EeV superimposed on the Swift – BAT density map smoothed with angular scale of 5 degrees**
Distance less than 200 Mpc.



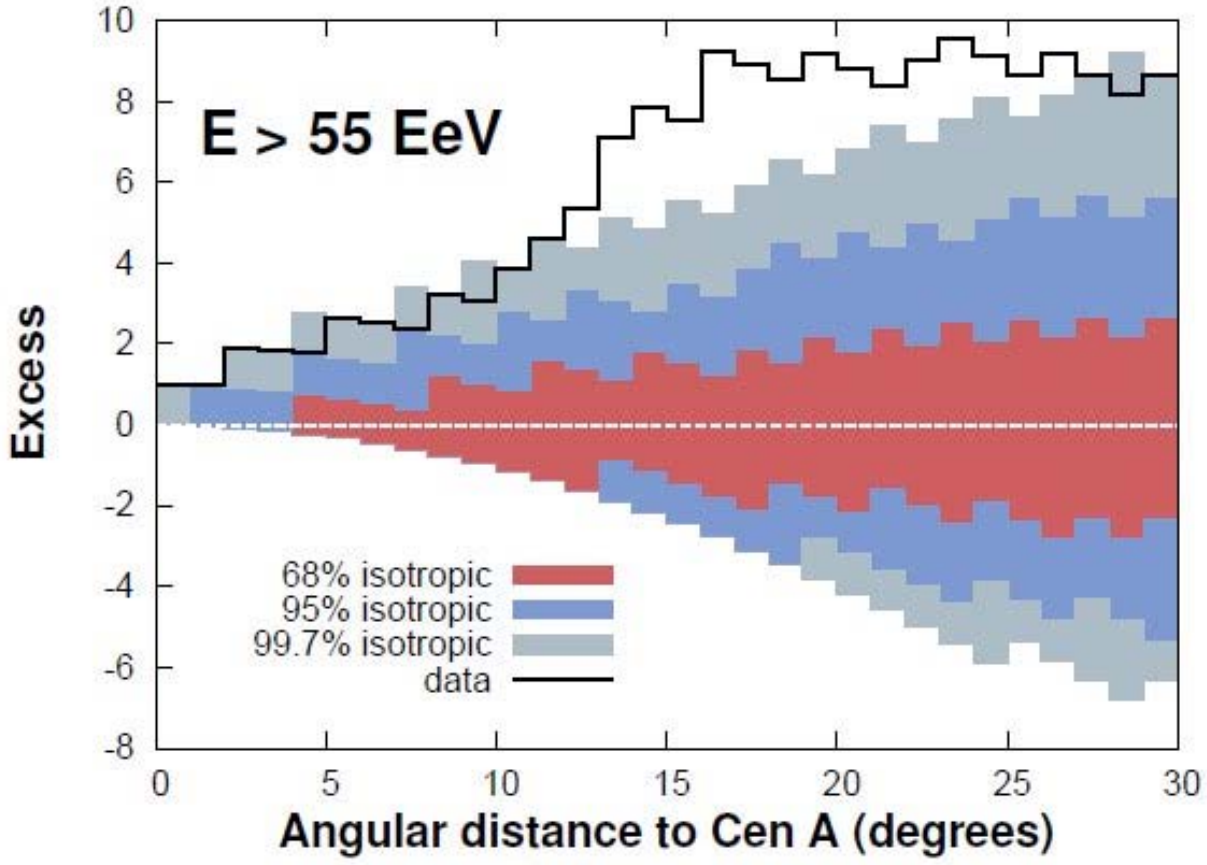
Clear excess in the region of Centaurus

A sizeable fraction of events come from the region of Cen A (AGN at ~ 4 Mpc)

Within 18^0 from Cen A we have 13 events (20% of the total) while we expect 3.2 for isotropic distribution.

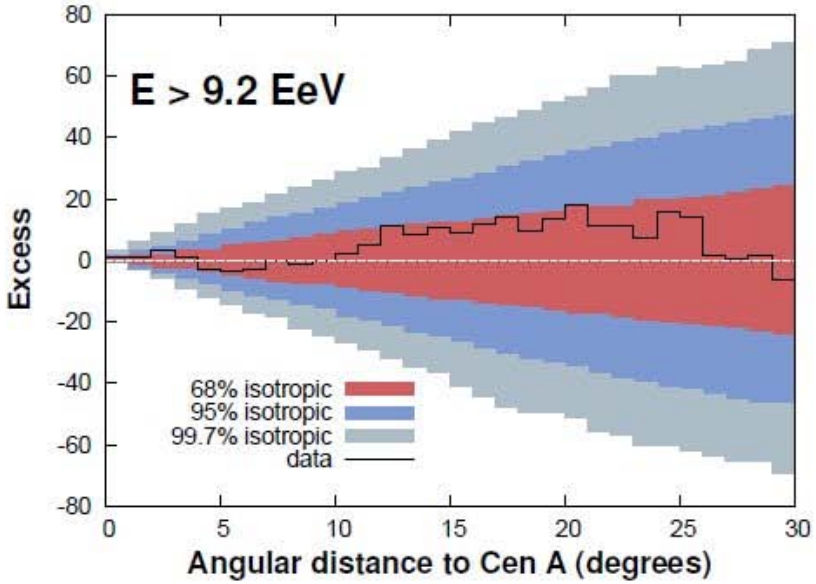
Most likely these particles don't come from Cen A but from Centaurus cluster, same direction but much further away , 40-50 Mpc, strong emitters of HI line. (Ghisellini et al. 2008)

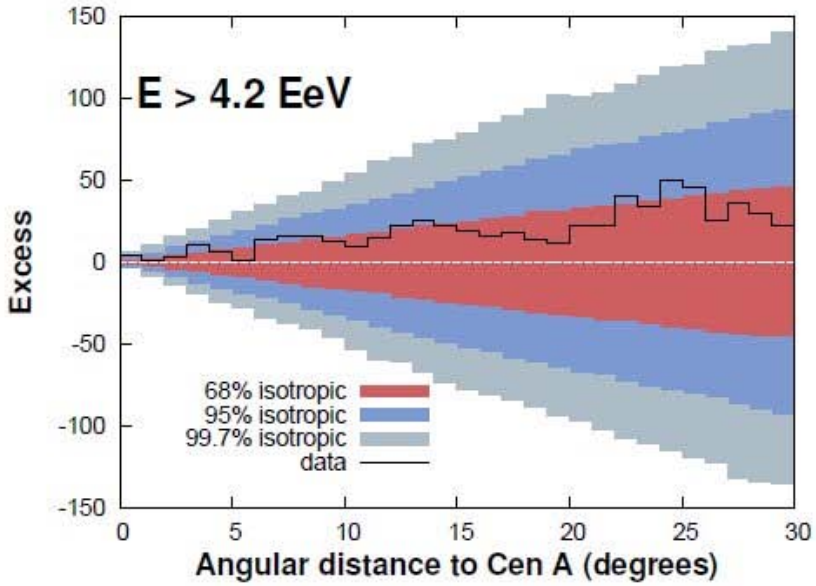
Auger

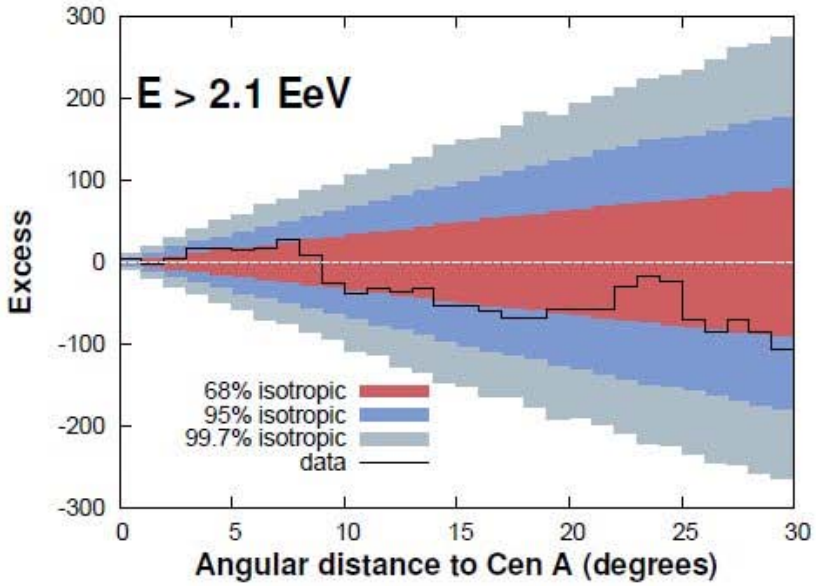


Auger

219
797
2997







Conclusions

- Shape of the energy spectrum well understood.
  Existence of GZK cut-off well established
  (Energy calibration to be improved)

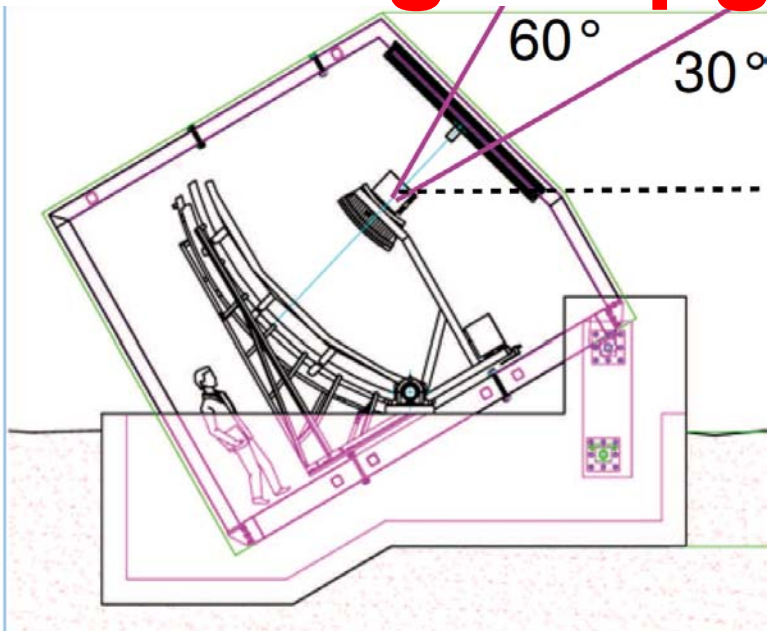
- Mass composition requires better understanding of systematic effects (difficult measurement)

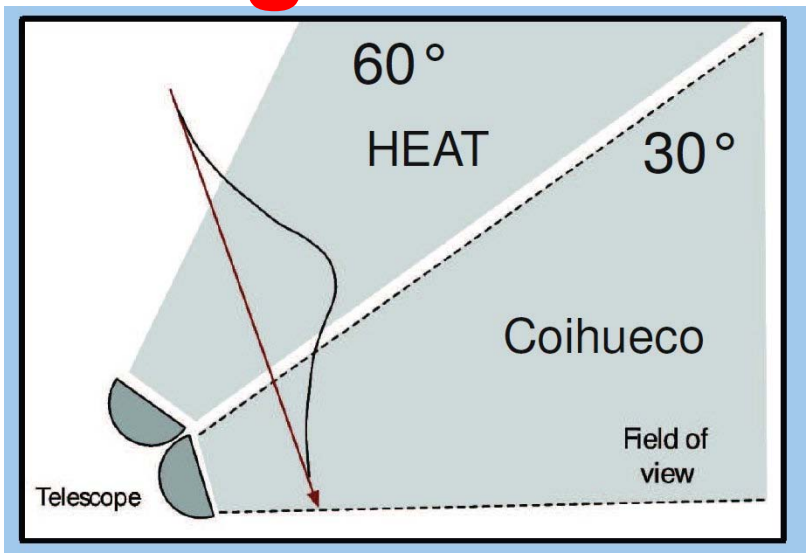
- Indication / evidence for correlation with extragalactic objects – Centaurus region
  transition from isotropy to anisotropy at the GZK

New developments

Auger upgrading

Tilted
HEAT
telescope





- **Infill – dense array, ½ standard spacing (~ 50 km^2)**
- **Three telescopes with higher elevation angle (30 – 60 degree)**

Reduction of minimum explored energy $10^{18} \rightarrow 10^{17}$ eV

10^{17} eV same energy as LHC.
Data on hadronic physics at LHC –> tuning of the simulation programs.
More reliable predictions on Xmax at higher energies

Radio R&D at Auger

Expect signal in the region about 10 – 100 MHz

R&D array of
~ 20 km^2

Few events in coincidence with FD, SD already observed !

PHYSICAL REVIEW D **78,** 032007 (2008)

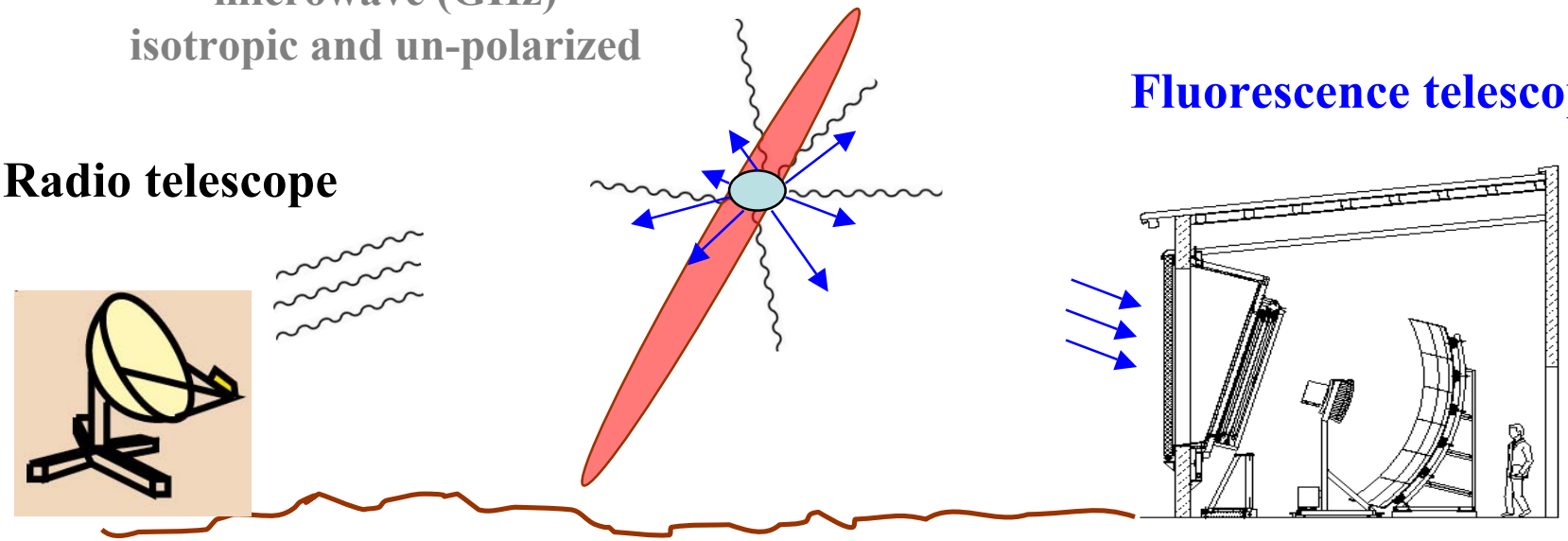
Observations of microwave continuum emission from air shower plasmas

P. W. Gorham,[1] N. G. Lehtinen,[1,*] G. S. Varner,[1] J. J. Beatty,[2] A. Connolly,[3] P. Chen,[4] M. E. Conde,[5] W. Gai,[5] C. Hast,[4] C. L. Hebert,[1,+] C. Miki,[1] R. Konecny,[5] J. Kowalski,[1] J. Ng,[4] J. G. Power,[5] K. Reil,[4] L. Ruckman,[1] D. Saltzberg,[3] B. T. Stokes,[1,‡] and D. Walz[4]

microwave (GHz)
isotropic and un-polarized

Radio telescope

Fluorescence telescope



Energy deposit → **plasma** $T_e \sim 10^5$ K

→ **Secondary electrons excite N_2 ⇒ fluorescence radiation**

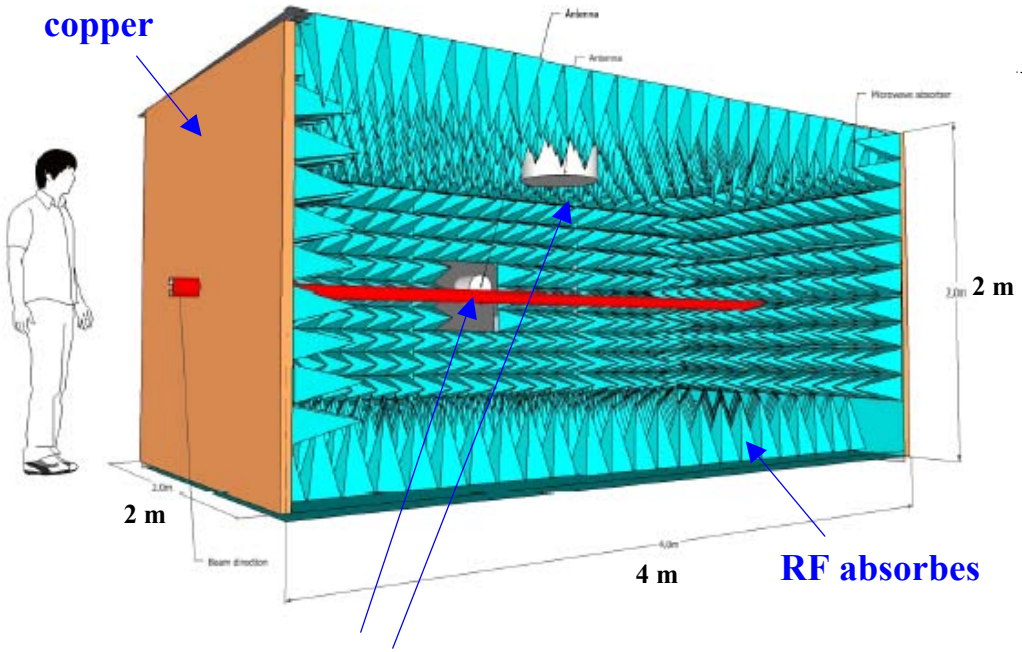
→ **Secondary electrons themselves produce their own emission like <u>bremsstrahlung in the field of neutral molecules</u>**

AMY: AIR MICROWAVE YIELD

Confirm and **measure** precisely the **absolute microwave yield** and its **frequency spectrum** in the range **between 1 and 25 GHz**

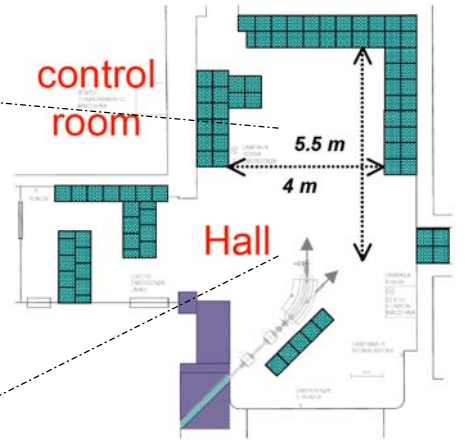
INFN
Roma Tor Vergata
Lecce - Aquila
Czech Republic
Sant. de Compostela

Anecoic Faraday chamber



Log periodic antennas
0.85-26.5 GHz
spectrum analyzer
high bandwidth oscilloscope

DAFNE
Beam Test Facility



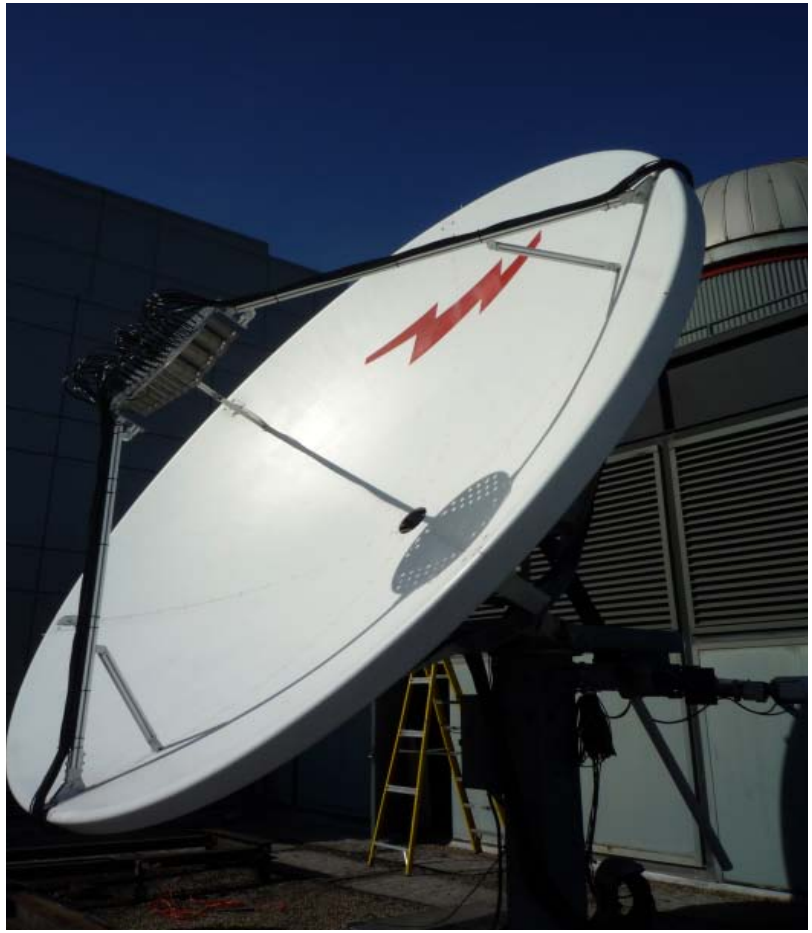
$$10^{10}\mathrm{e}^{-}/\mathrm{bunch} \times 700\ \mathrm{MeV} =$$

$$= 7\ 10^{18}\ \mathrm{eV}$$

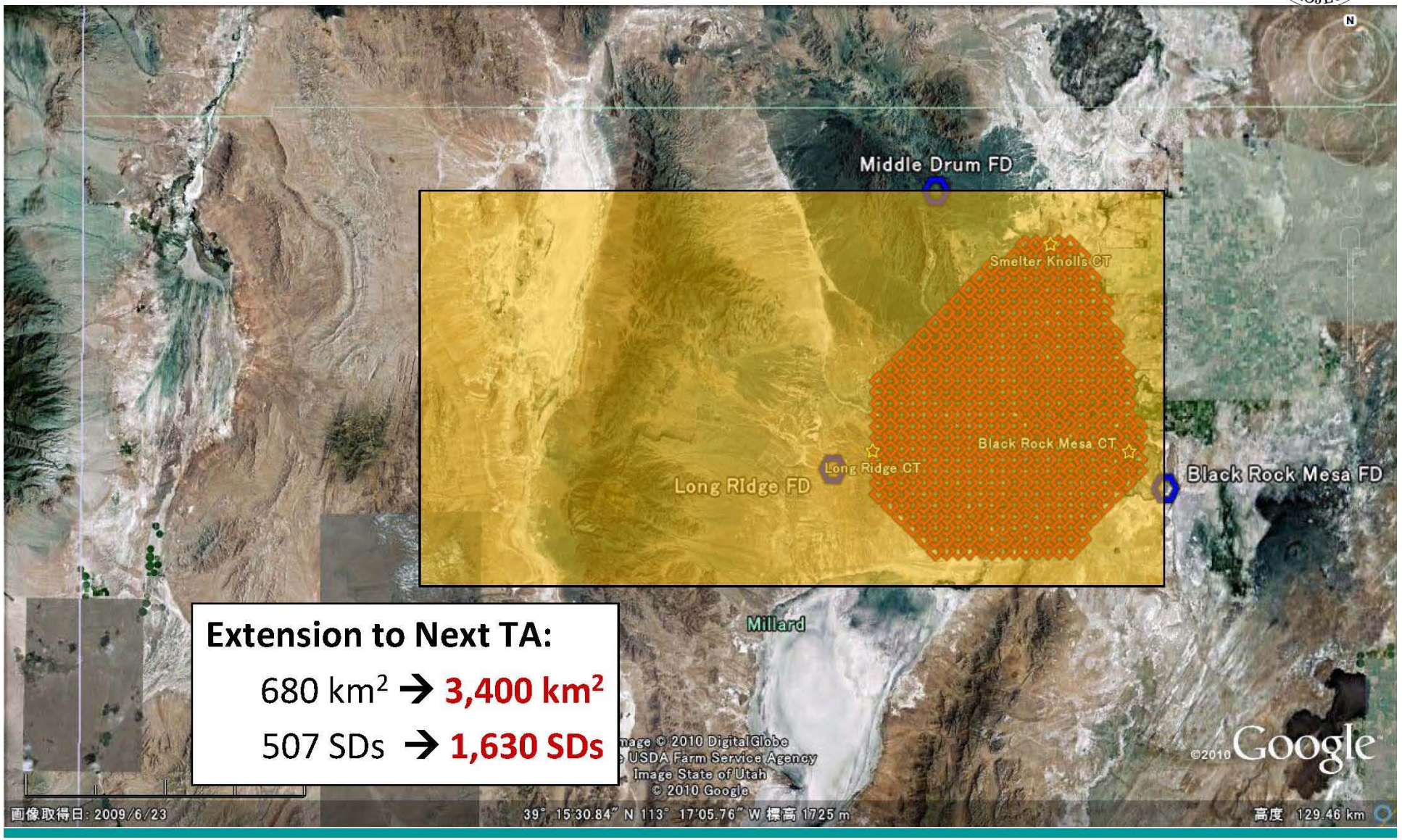
First test: July

Prototypes to be installed at the Auger Observatory

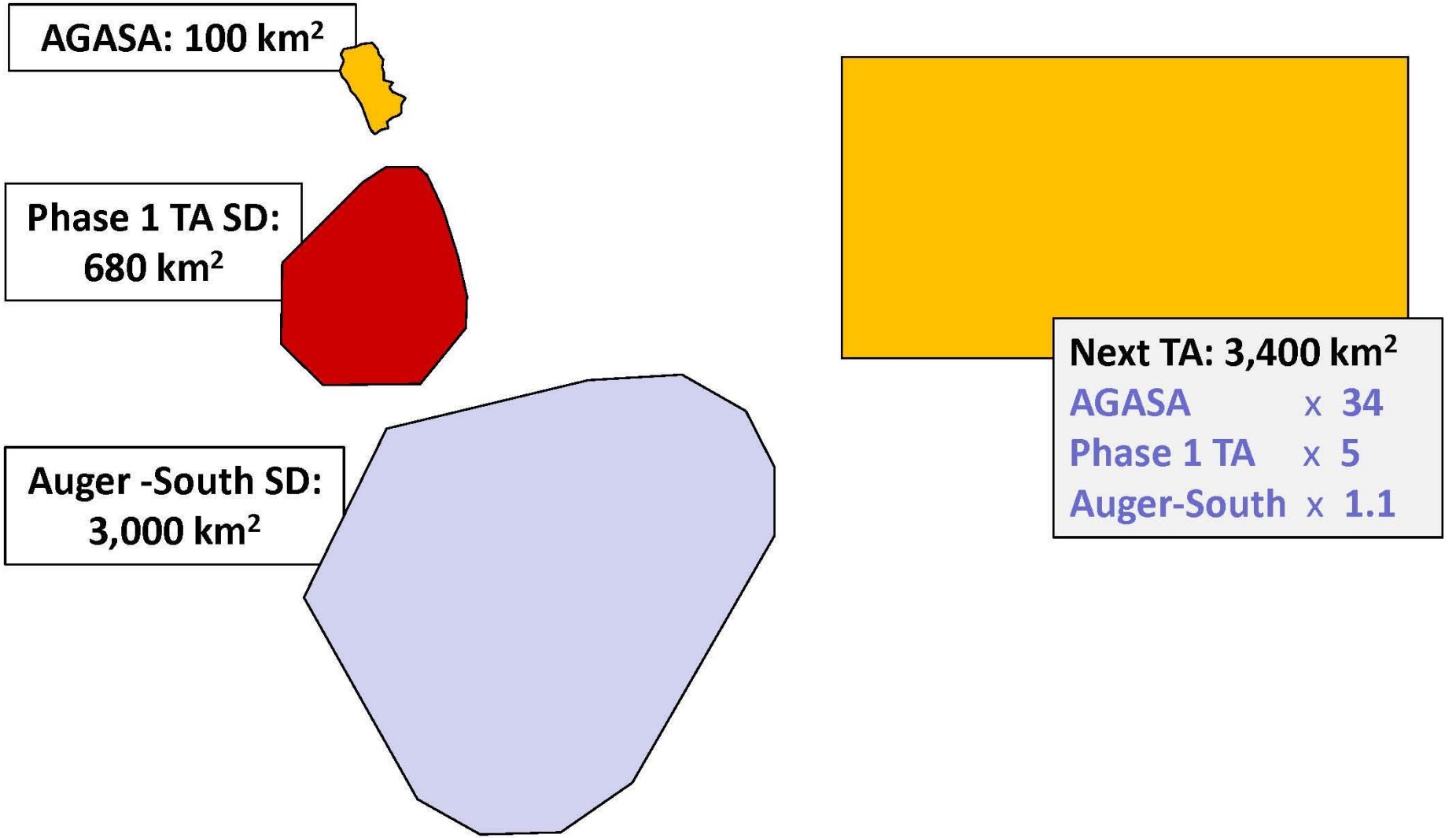
4.5 m dish



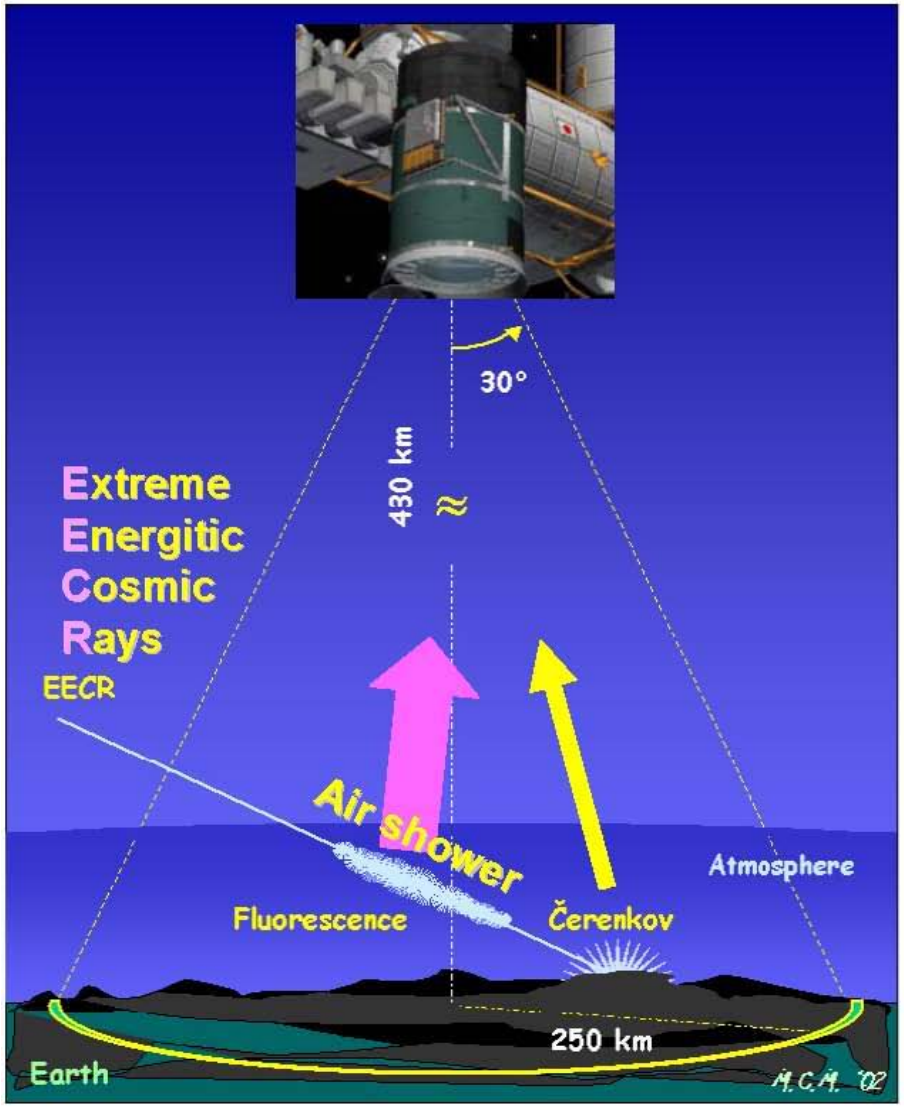
Current TA and Next TA



Next TA and other detectors



JEM-EUSO Observational Principle



JEM-EUSO is a new type of observatory on board the International Space Station (ISS), which observes transient luminous phenomena occurring in the earth's atmosphere.

The telescope has a super wide field-of-view(60°) and a large diameter(2.5m).

JEM-EUSO mission will initiate particle astronomy at ~10^{20}eV.

JEM-EUSO telescope observes fluorescence and Cherenkov photons generated by air showers created by extreme energetic cosmic rays