Ecole de GIF 2013

Principes et méthodes de détection : Particules chargées au sol (II)

INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

Tiina Suomijärvi
Institut de Physique Nucléaire
IN2P3/CNRS, Université Paris-Sud
France

Contents

Ground experiments

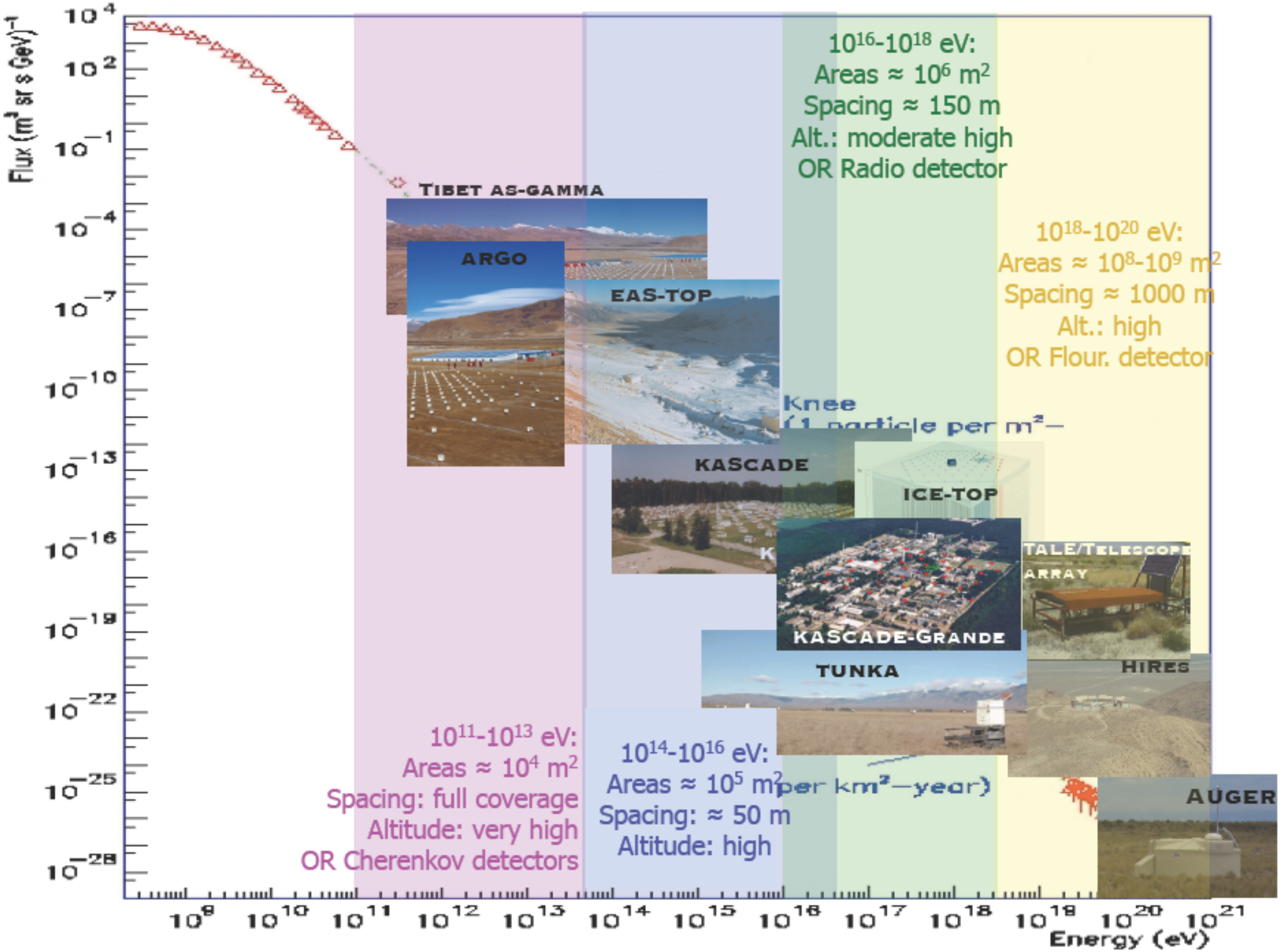
Pierre Auger Observatory

Other ground detectors:

- Telescope Array
- LHAASO

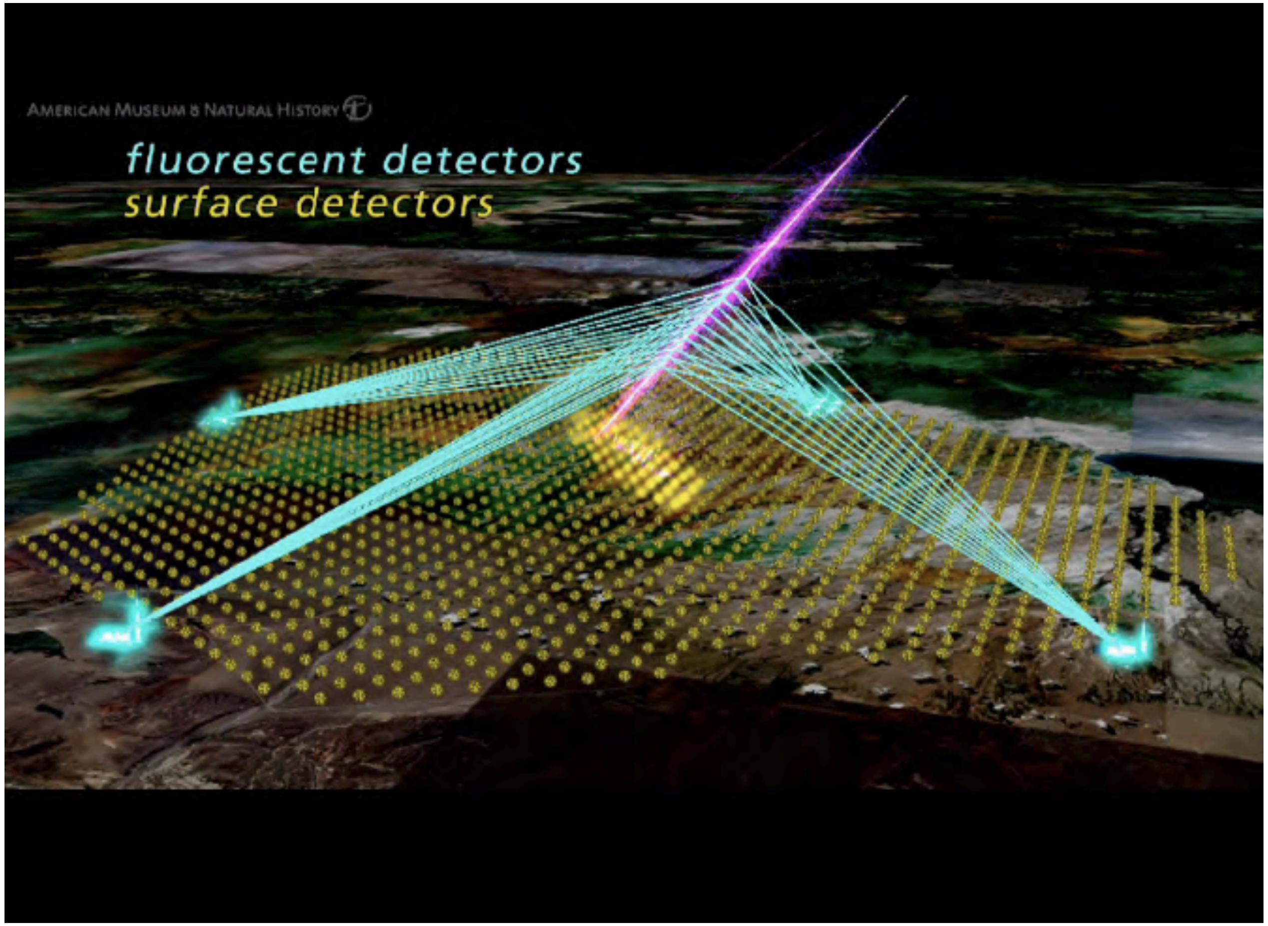
Conclusions

Ground experiments



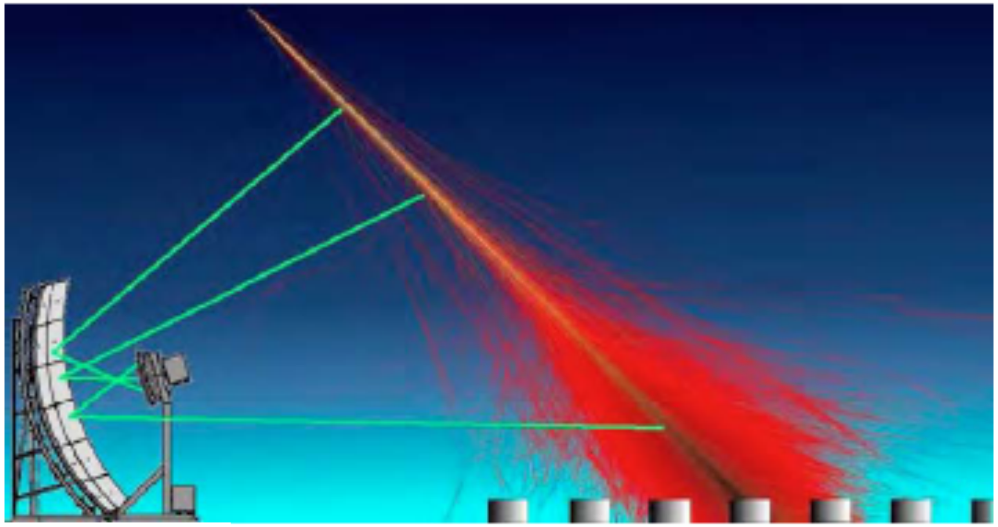
The Pierre Auger Observatory

Surface Detector (SD) array + Fluorescence Detectors (FD)



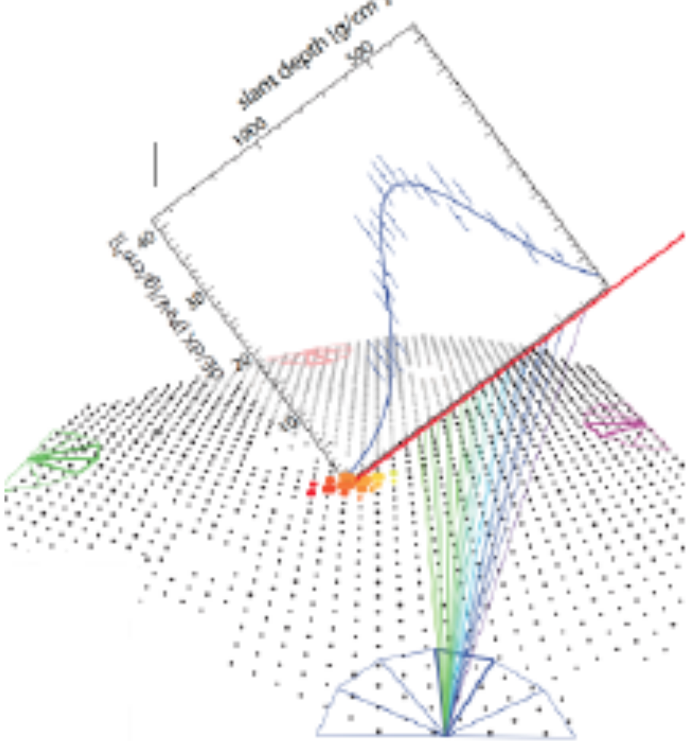
- Nearly calorimetric energy calibration of the fluorescence detector transferred to the event gathering power of the surface array.
- A complementary set of mass sensitive shower parameters.
- Different measurement techniques force understanding of systematic uncertainties
- Better determination of the angular and core position

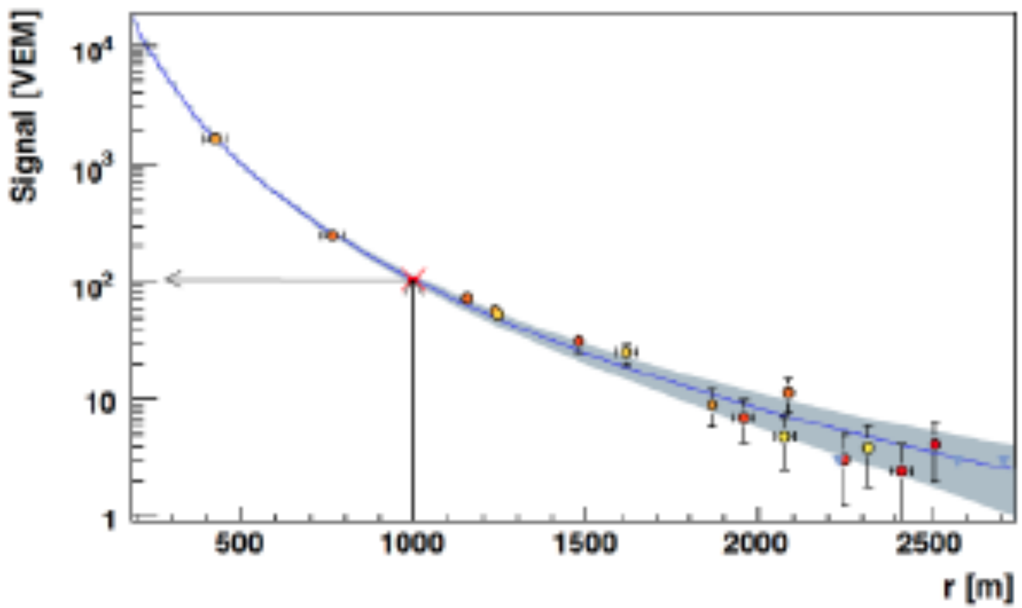
Hybrid measurement

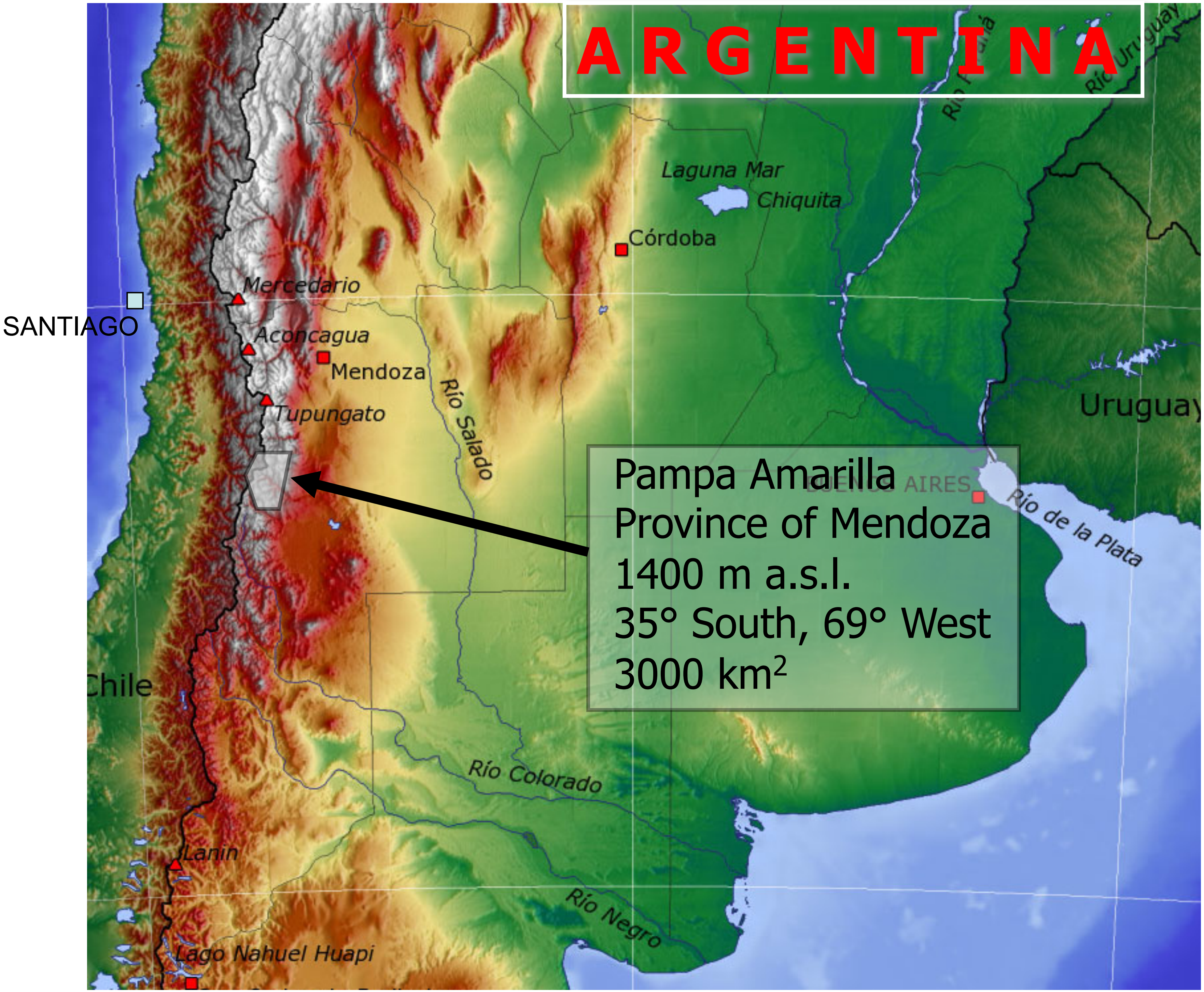


FD: 13% duty cycle
Calorimetric measurement

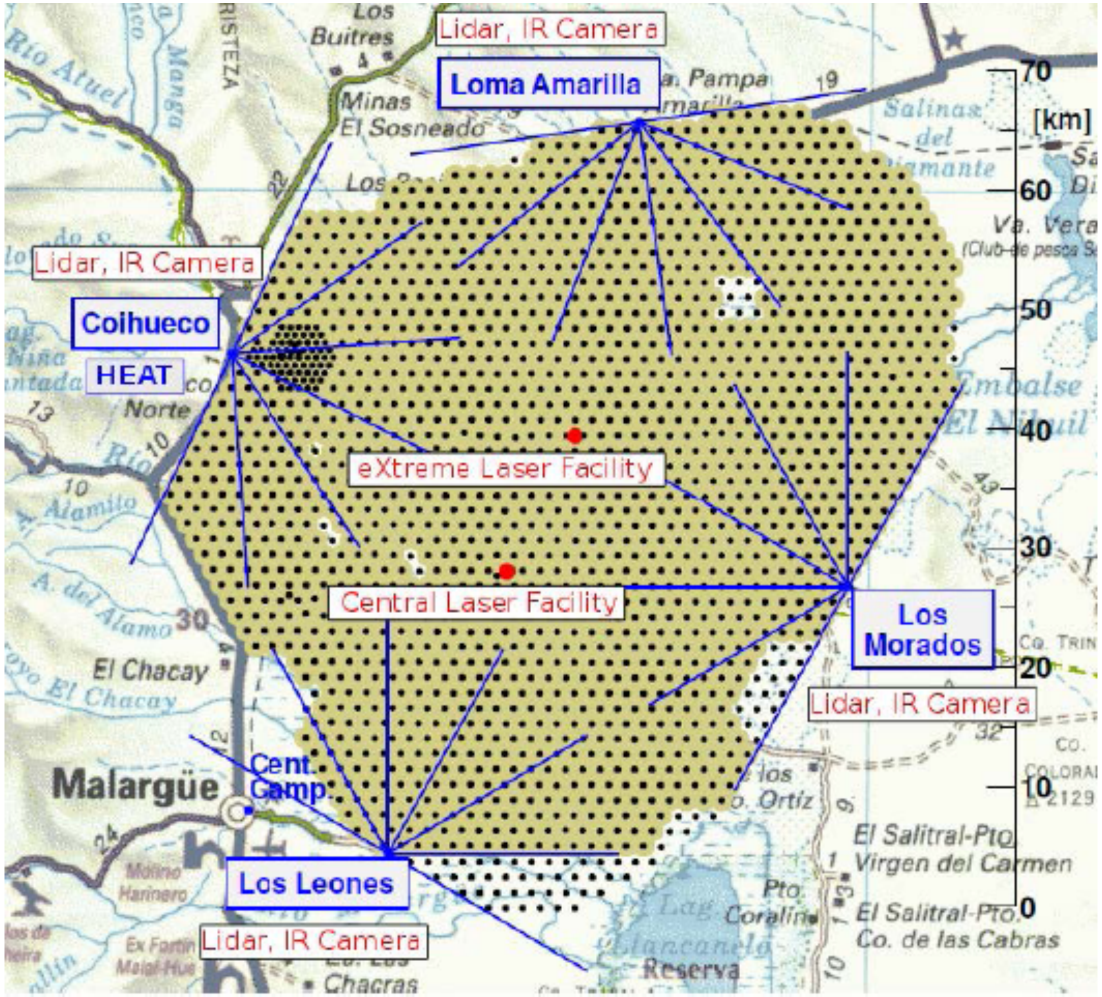
SD: 100% duty cycle






ARGENTINA
Laguna Mar
Chiquita
Córdoba
Mercedario
SANTIAGO
Aconcagua
Mendoza
Río Salado
Tupungato
Uruguay
Pampa Amarilla
Province of Mendoza
1400 m a.s.l.
35° South, 69° West
3000 km²
AIRES
Río de la Plata
Chile
Río Colorado
Lanin
Río Negro
Lago Nahuel Huapi

Layout



Surface Array

1600 detector stations

1.5 Km spacing

3000 Km²

INFILL array:

60 detector stations

750 m spacing

Fluorescence Detectors

4 Telescope enclosures

6 Telescopes per enclosure

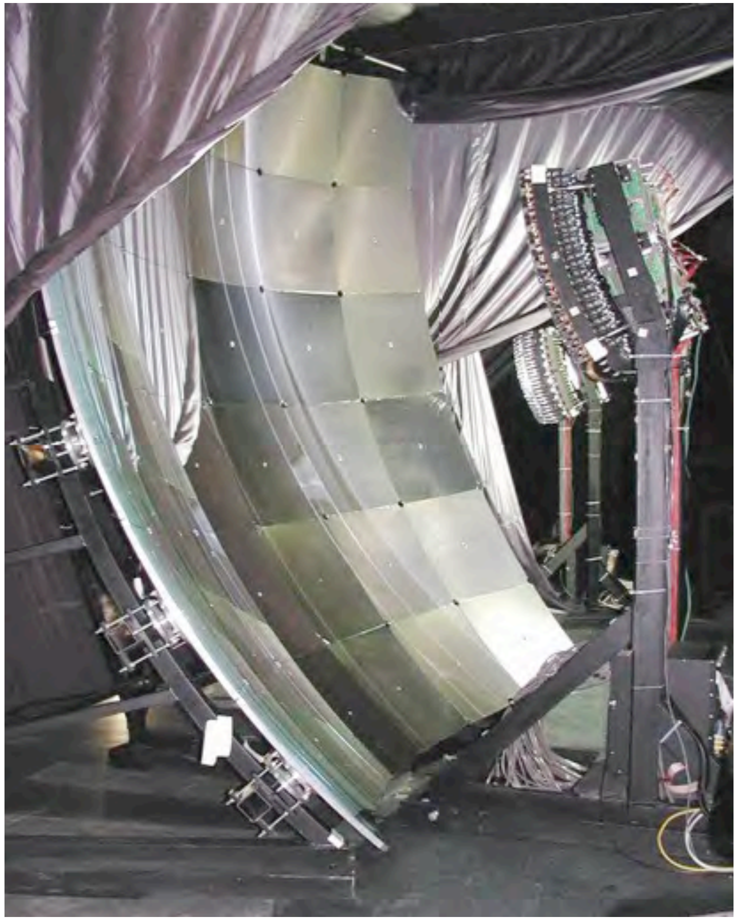
24 Telescopes total

HEAT: 3 Telescopes

The full efficiency of the SD trigger is reached at 3 10^{18} eV.

For the Infill array the full efficiency is reached at 3 10^{17} eV.

FD telescope and SD detector

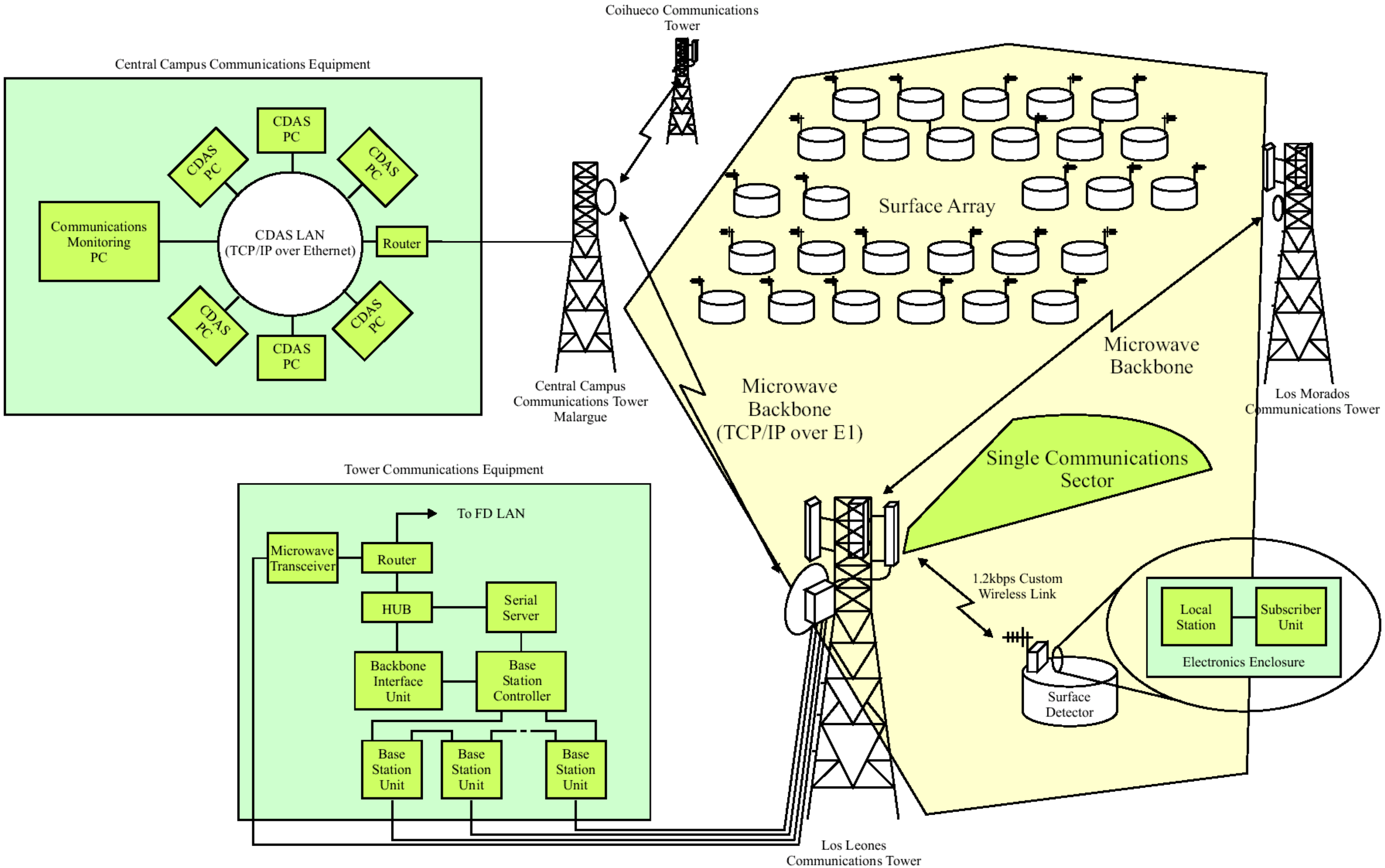


Schmidt telescopes using 13 m^2 mirrors.
UV optical filter.
Camera with 440 Photonis XP 3062 PMTs.

3.6 m diameter water tank containing a sealed liner with a reflective inner surface.
12 000 l of ultra-high purity water.
Three 9 inch PMTs, Photonis XP 1805, look downwards through windows of clear polyethylene.

Fluorescence detectors (FD)

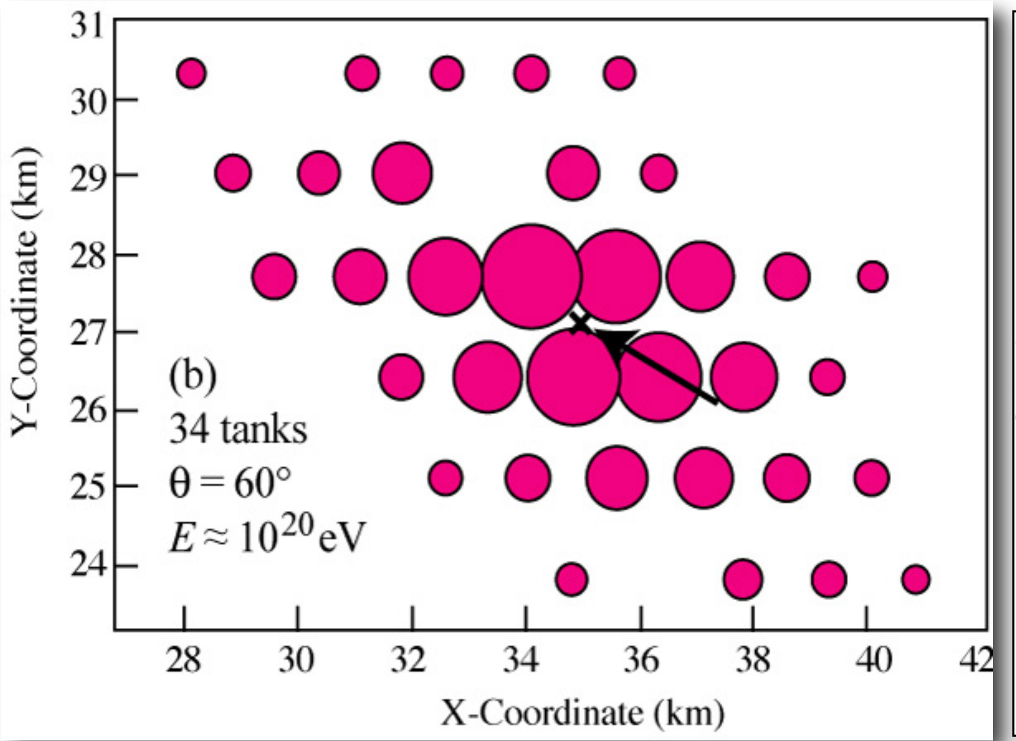
Telecommunication system

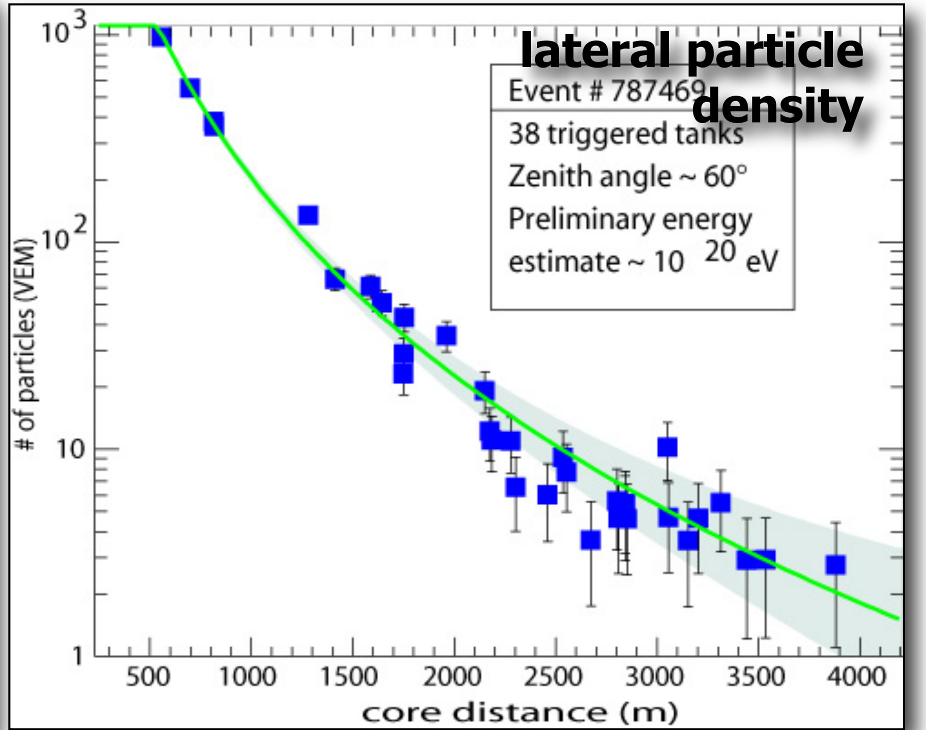


Construction… sometimes difficult

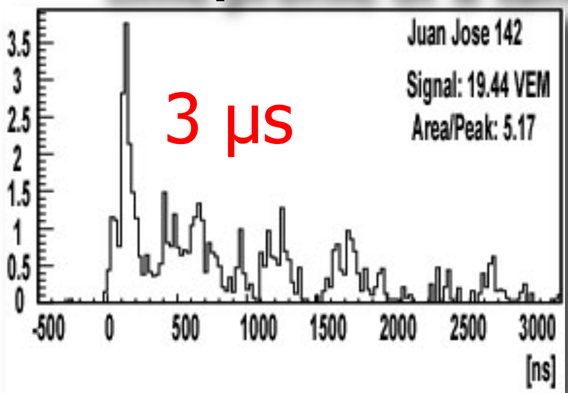
Construction 2000-08
Data taking started 2004

SD reconstruction





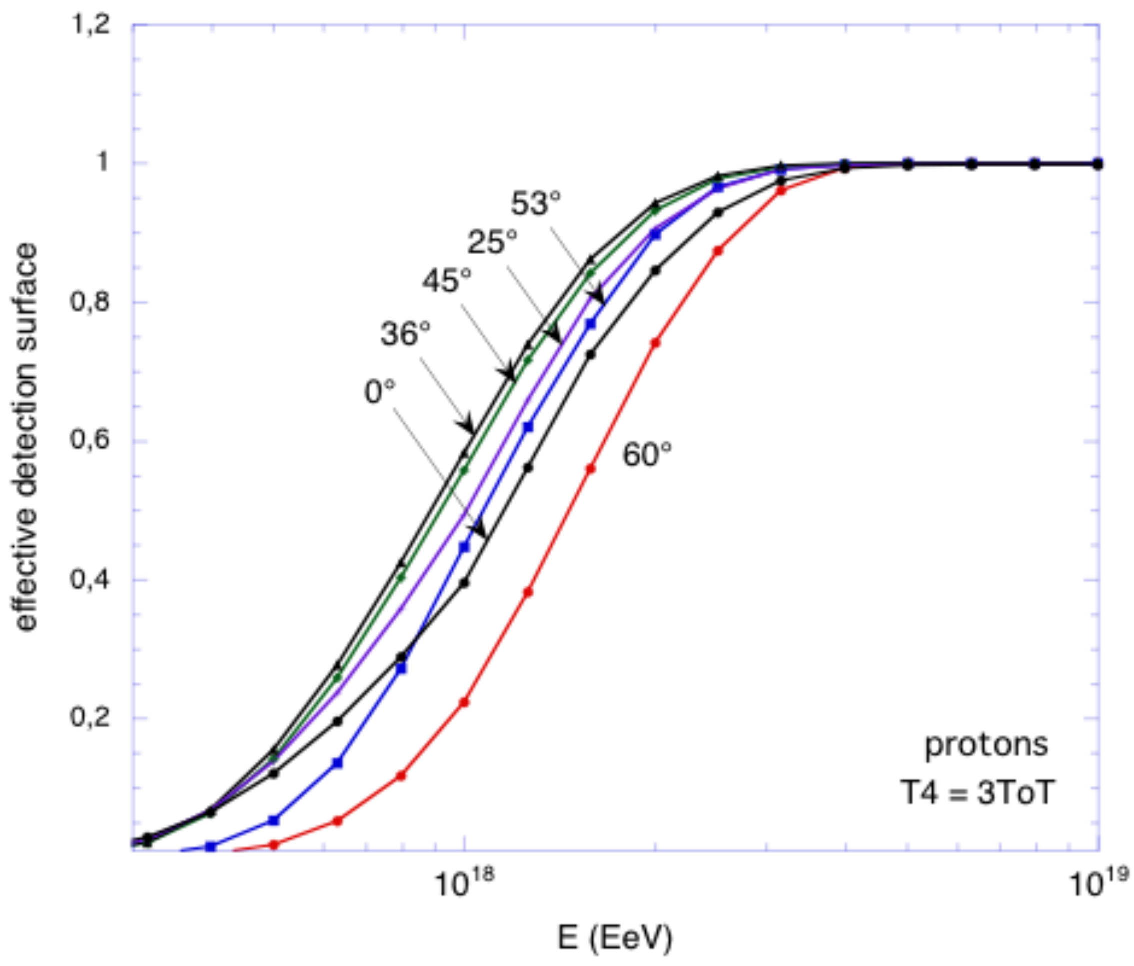
time profile of a tank

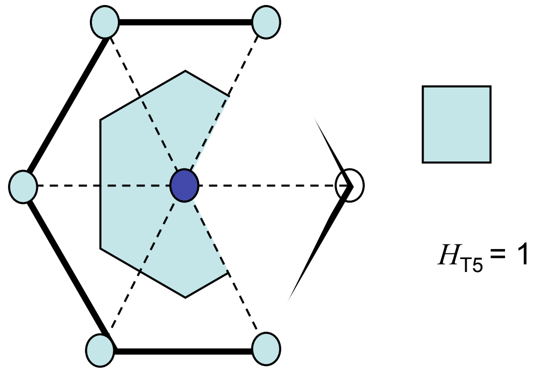


✓Reconstruct angle (arrival time)
✓Fit lateral particle density by LDF
✓Extract S(1000): signal density at 1000m
✓Use hybrid events to correlate S(1000) with FD energy

SD acceptance

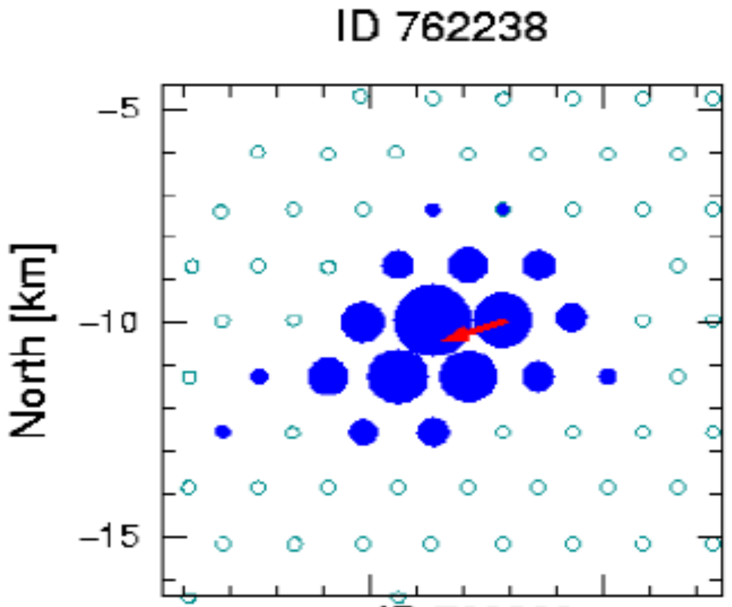
Effective surface of an elementary hexagonal cell:

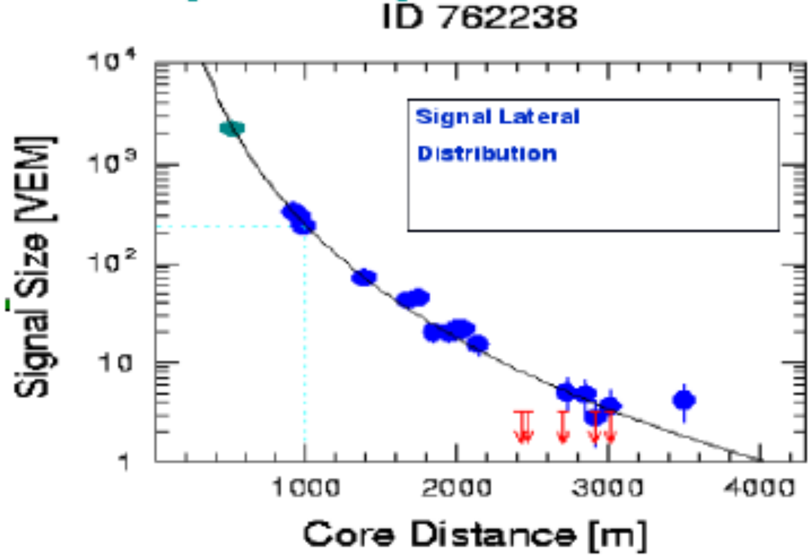


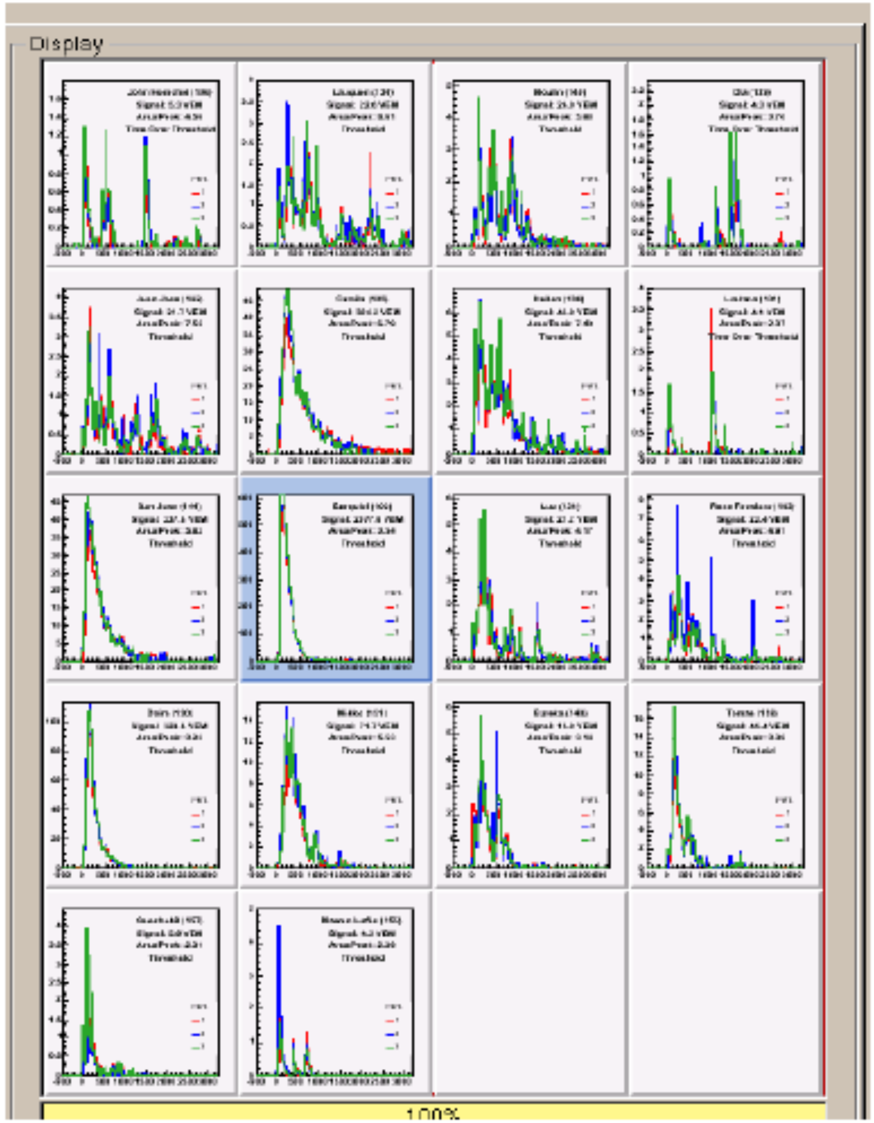


E > 3 EeV: geometrical acceptance

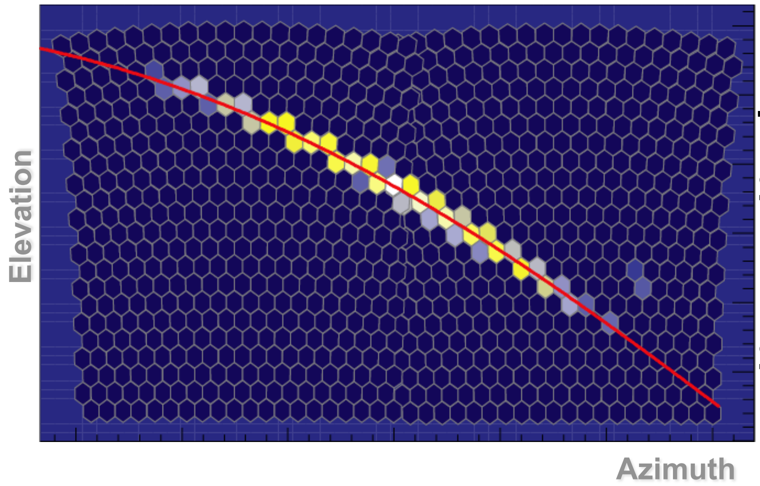
A typical vertical shower event





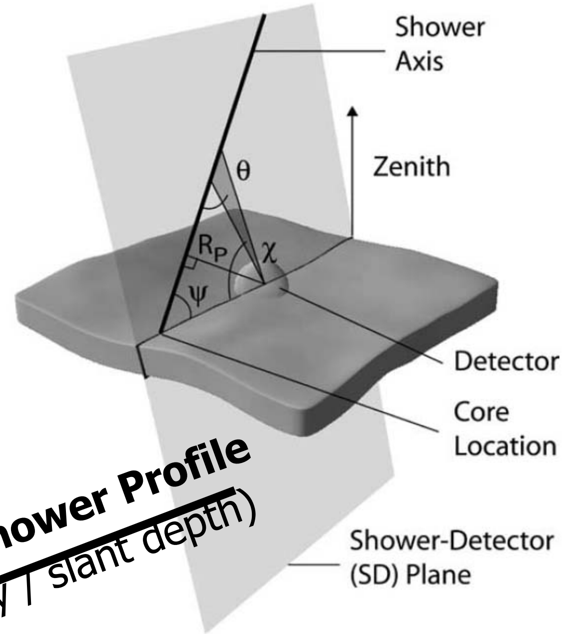


FD reconstruction



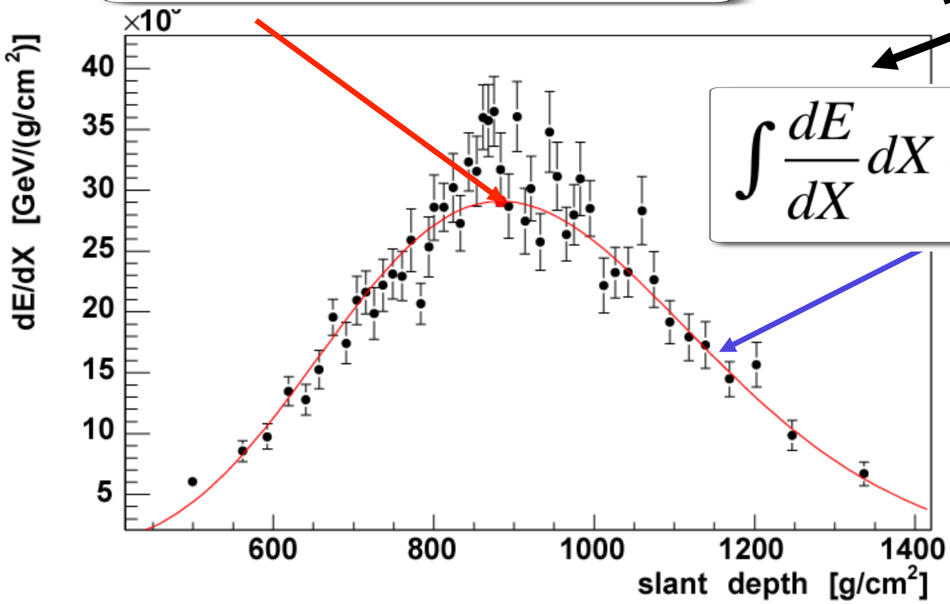
Track:
Shower Detector Plane (SDP)

Evolution with time:
Shower axis in SDP

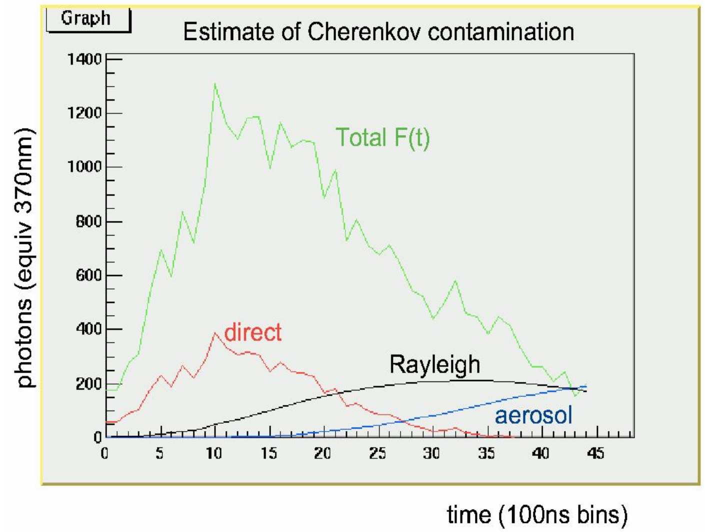


Longitudinal Shower Profile
(particle density / slant depth)

X_{max} ~ ln(E_0/A)   (MC Sim.)



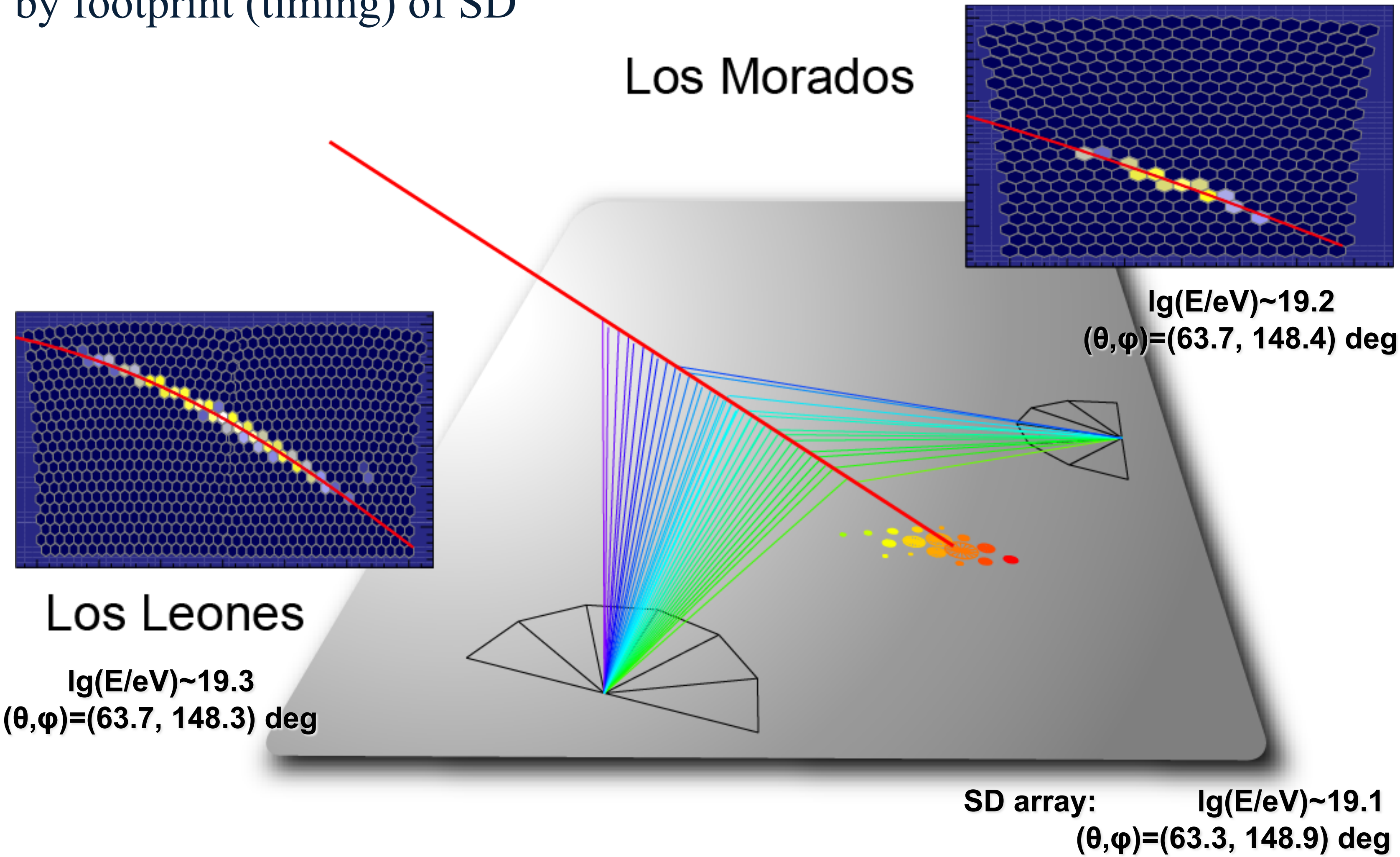
$$\int \frac{dE}{dX} dX \sim E$$



Calorimetric measurement!

Stereo hybrid observations

Advantage of hybrid:
Shower axis reconstraction improved
by footprint (timing) of SD



FD energy uncertainty

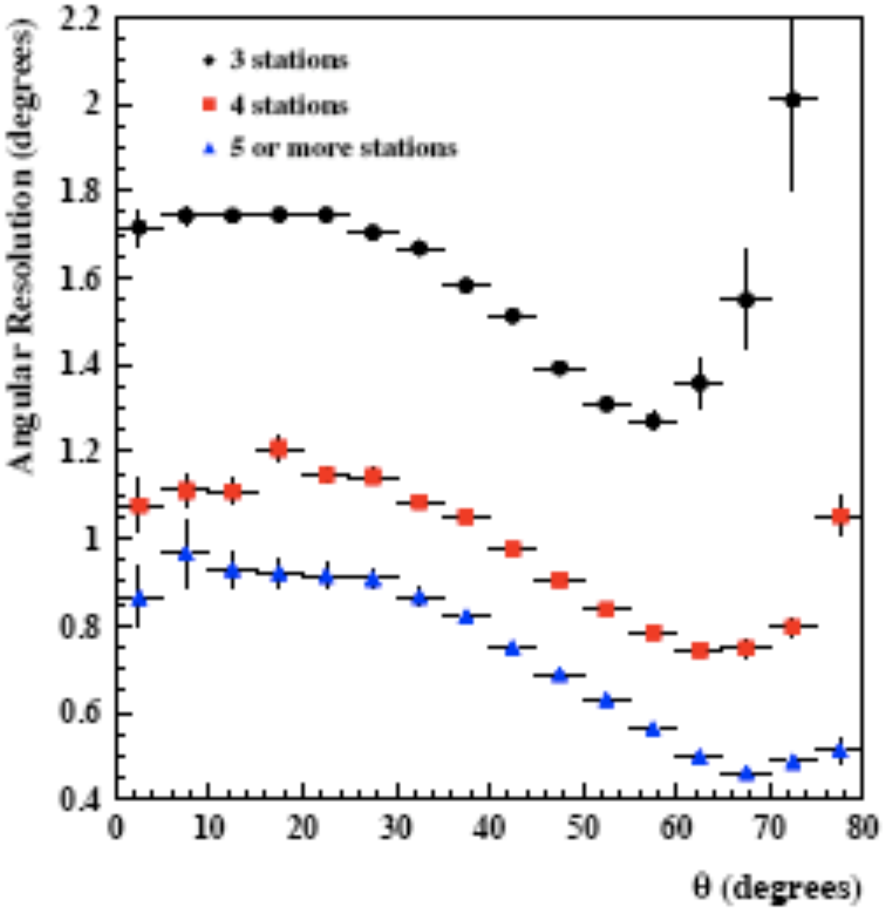
Absolute fluorescence yield	3.4%	
Fluores. spectrum and quenching param.	1.1%	
Sub total (Fluorescence Yield)	**3.6%**	**14%**
Aerosol optical depth	3% ÷ 6%	
Aerosol phase function	1%	
Wavelength dependence of aerosol scattering	0.5%	
Atmospheric density profile	1%	
Sub total (Atmosphere)	**3.4% ÷ 6.2%**	**5% ÷ 8%**
Absolute FD calibration	9%	
Nightly relative calibration	2%	
Optical efficiency	3.5%	
Sub total (FD calibration)	**9.9%**	**9.5%**
Folding with point spread function	5%	
Multiple scattering model	1%	
Simulation bias	2%	
Constraints in the Gaisser-Hillas fit	3.5% ÷ 1%	
Sub total (FD profile rec.)	**6.5% ÷ 5.6%**	**10%**
Invisible energy	**3% ÷ 1.5%**	**4%**
Statistical error of the SD calib. fit	**0.7% ÷ 1.8%**	
Stability of the energy scale	**5%**	
TOTAL	**14%**	**22%**

uncertainties on previous energy scale

improvement in each sector with the exception of FD cal. (largest contribution) work in progress to reduce it

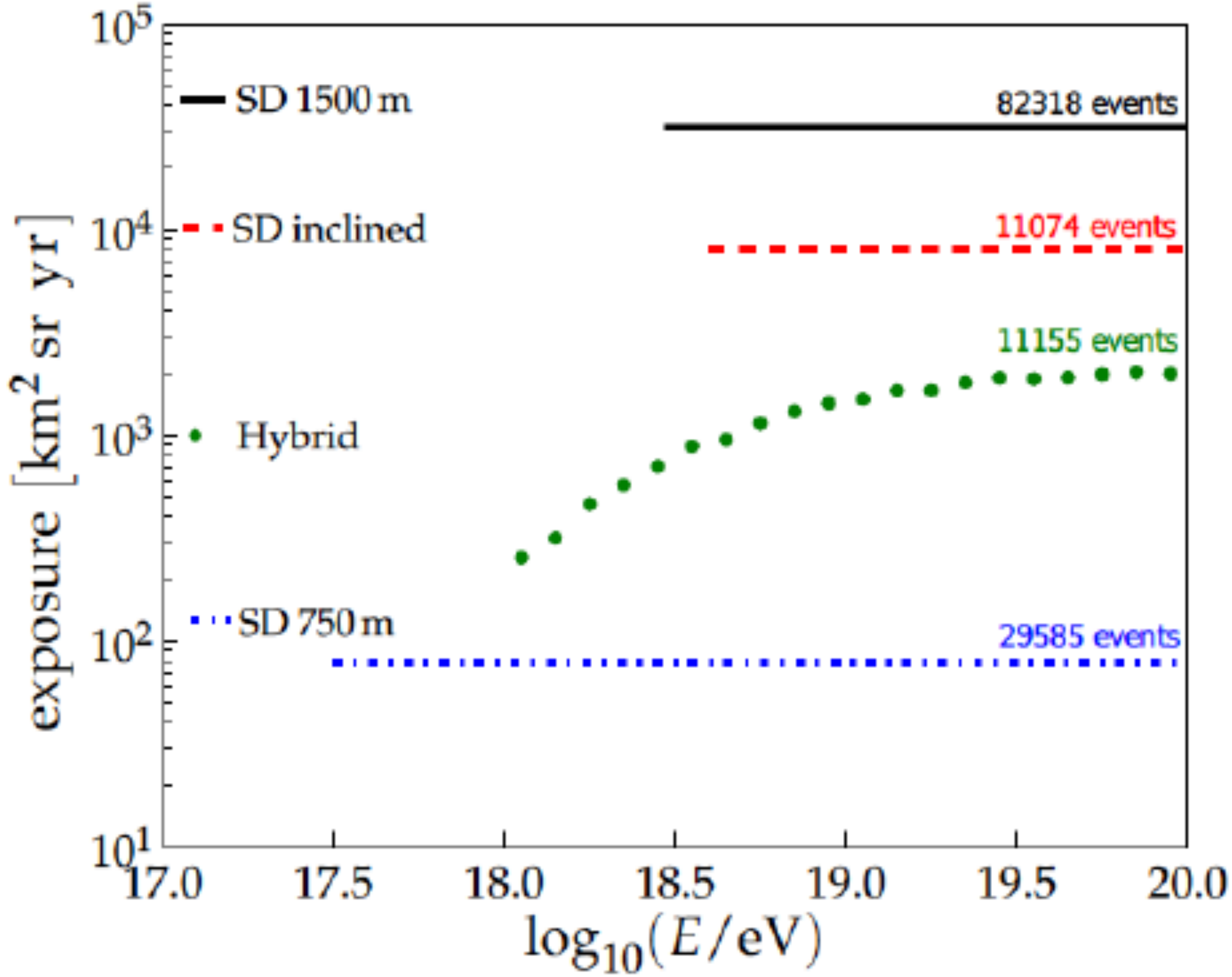
1 EeV and 10EeV

Angular resolution



Angular resolution of the surface detector about 1°. Hybrid events 0.6° .

Exposure



32 000 km^2 sr yr

Energy spectrum: Constant Intensity Cut

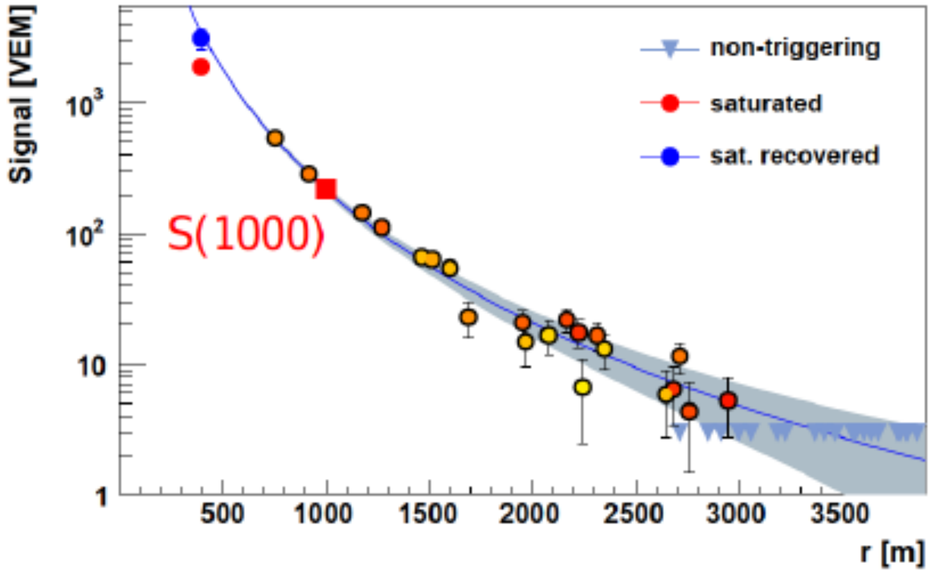
Use SD data above 3 EeV: Geometrical acceptance and good statistics
Use FD energy calibration (hybrid data): Calorimetric energy measurement and no uncertainty due to hadronic models and composition

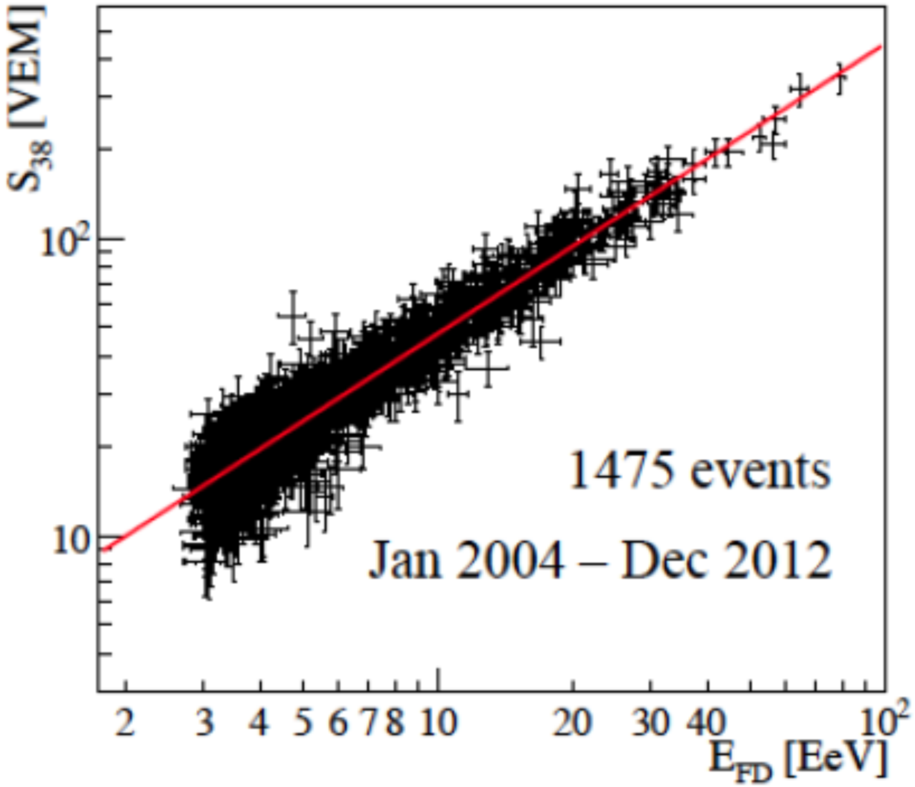
- ✓ Slant depth of the SD varies from 870 g/cm^2 for vertical showers to 1740 g/cm^2 for zenith angle of 60°
- ✓ S(1000) signal is attenuated at large slant depth: dependence on zenith angle determined empirically
- ✓ Isotropic intensity of cosmic rays: flat distribution as a function of $\sin^2 \theta$

=> Extract dependence of S(1000) on zenith angle

- ✓ Given S(1000) and θ for any measured shower S38= S(1000)/ CIC(θ)
- ✓ CIC method allows to correct S(1000) for zenith angle dependence

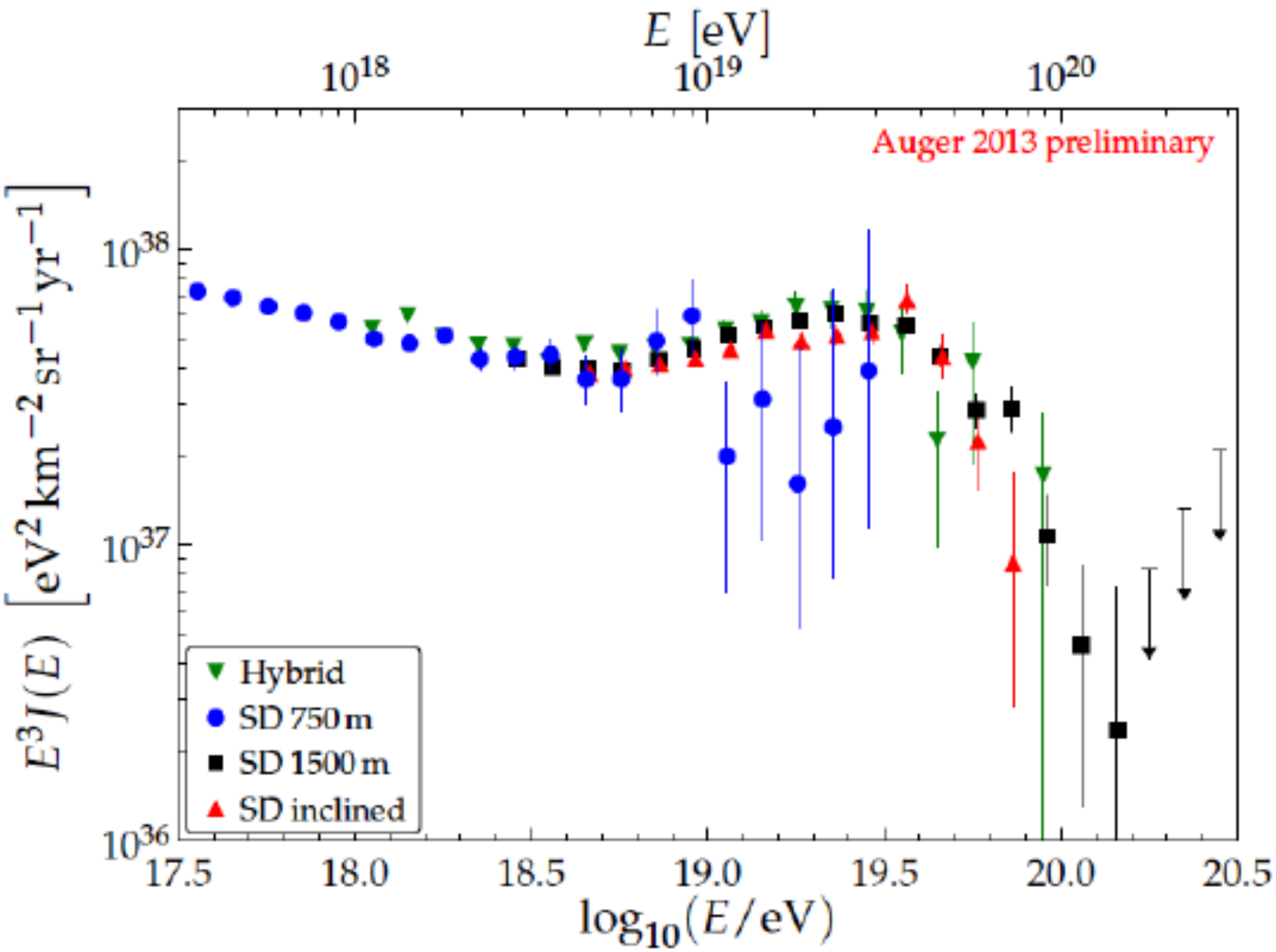
Calibration of SD by FD





$$E_{FD} = A S_{38}^{B}$$

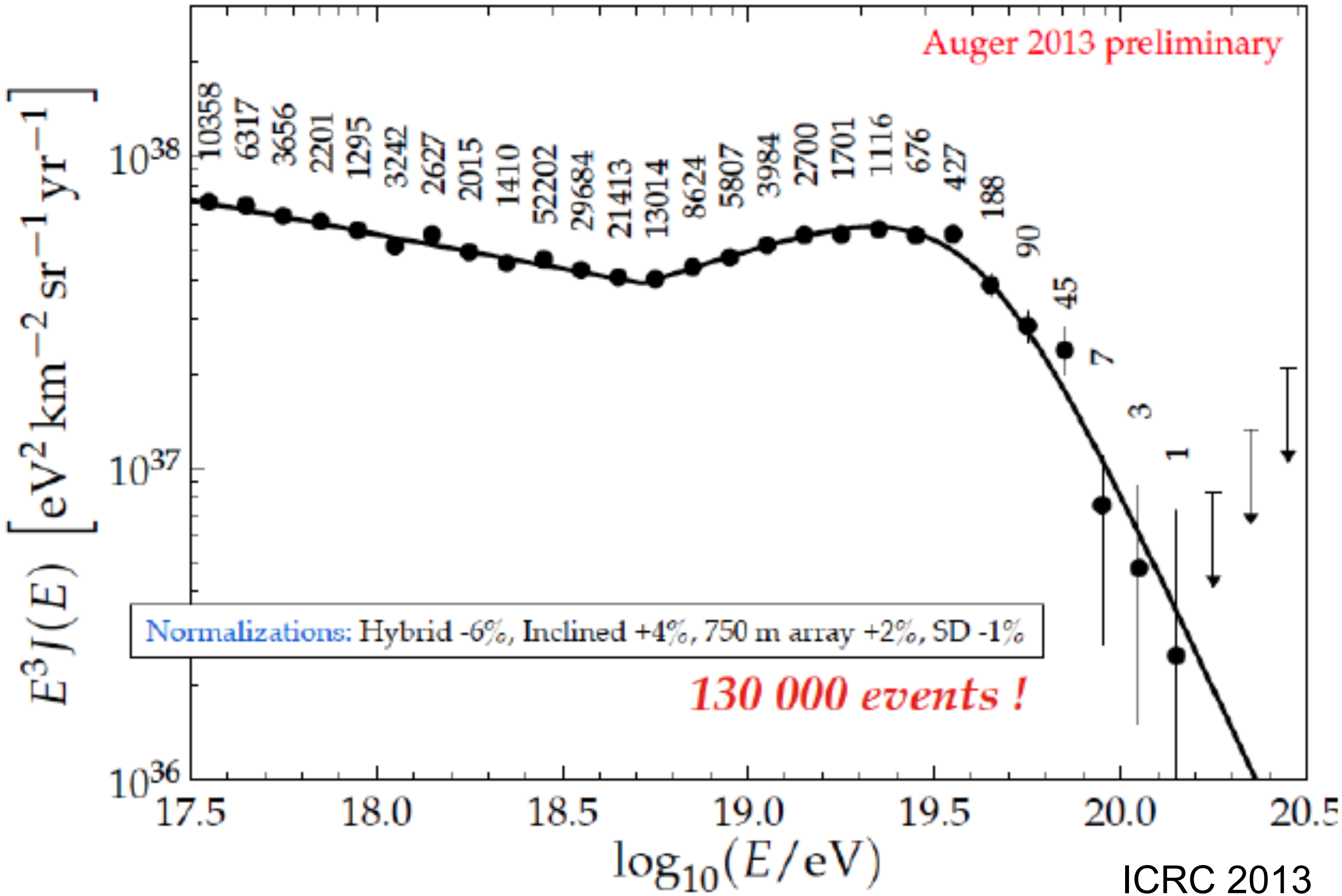
Energy spectrum



ICRC 2013

- Sharp angle at around 4 EeV
- Suppression above 50 EeV

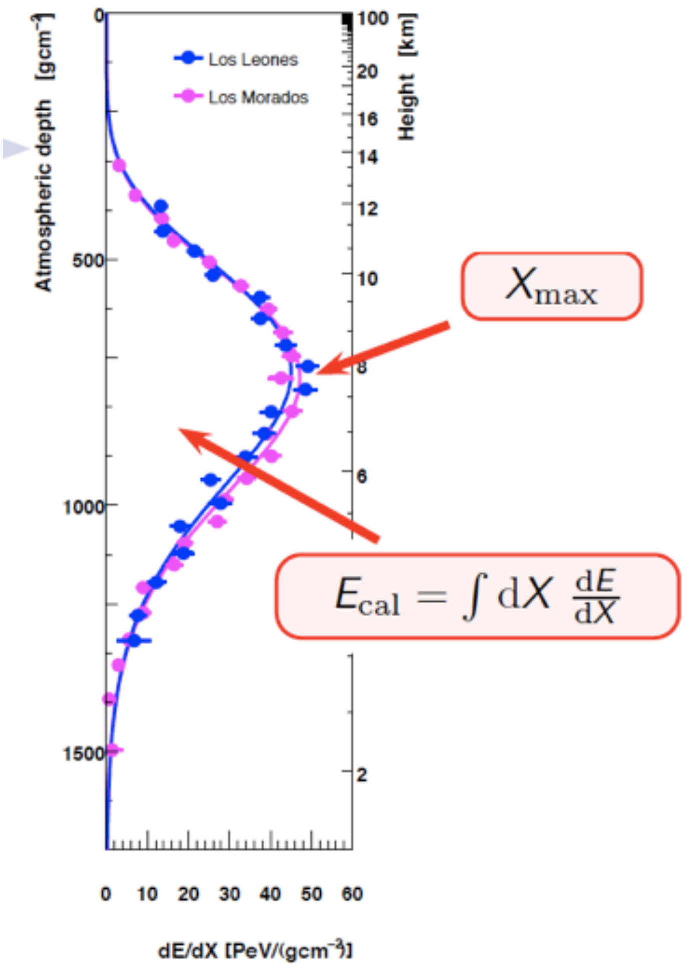
Combined energy spectrum

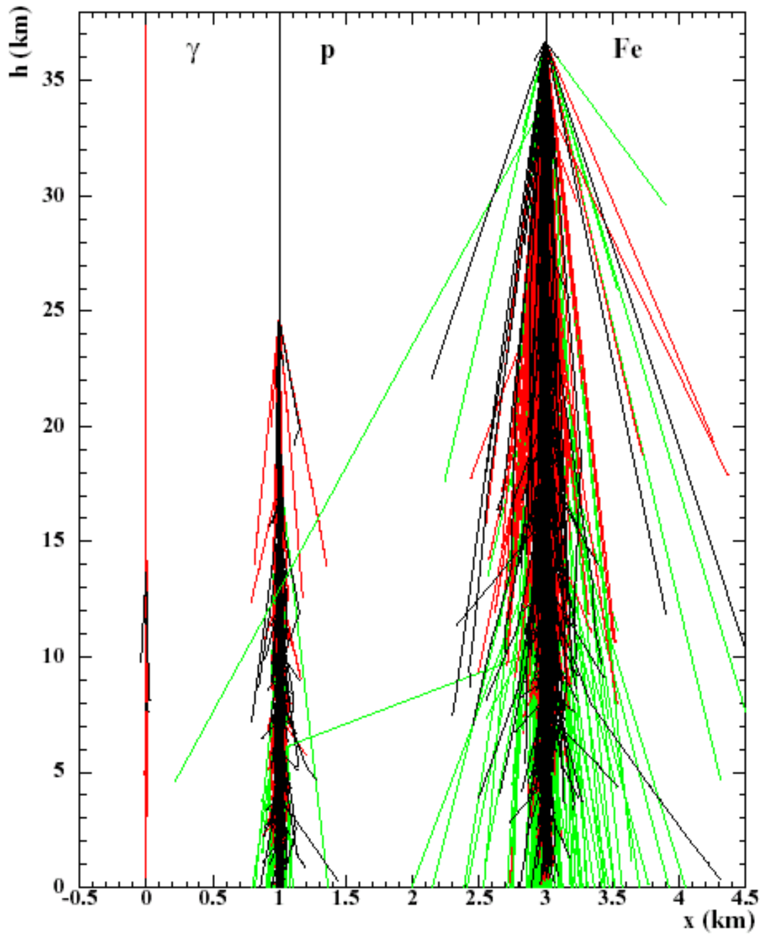


ICRC 2013

761 events above $10^{19.5}$ eV, 4 above 10^{20} eV

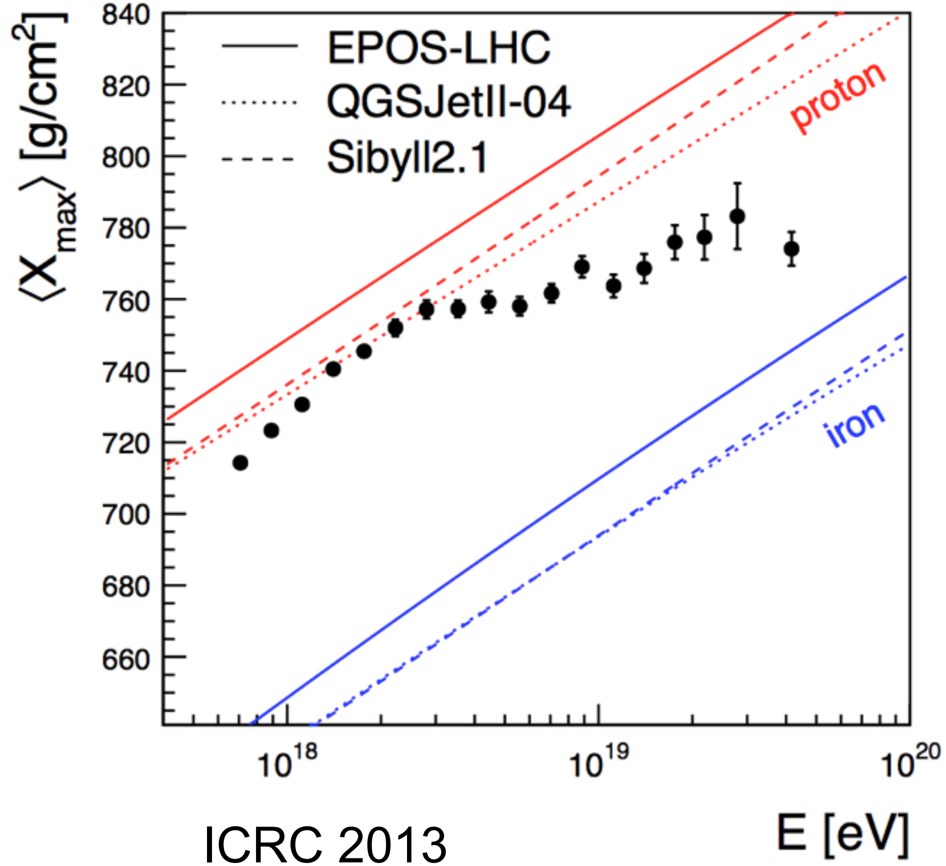
Mass sensitive parameters



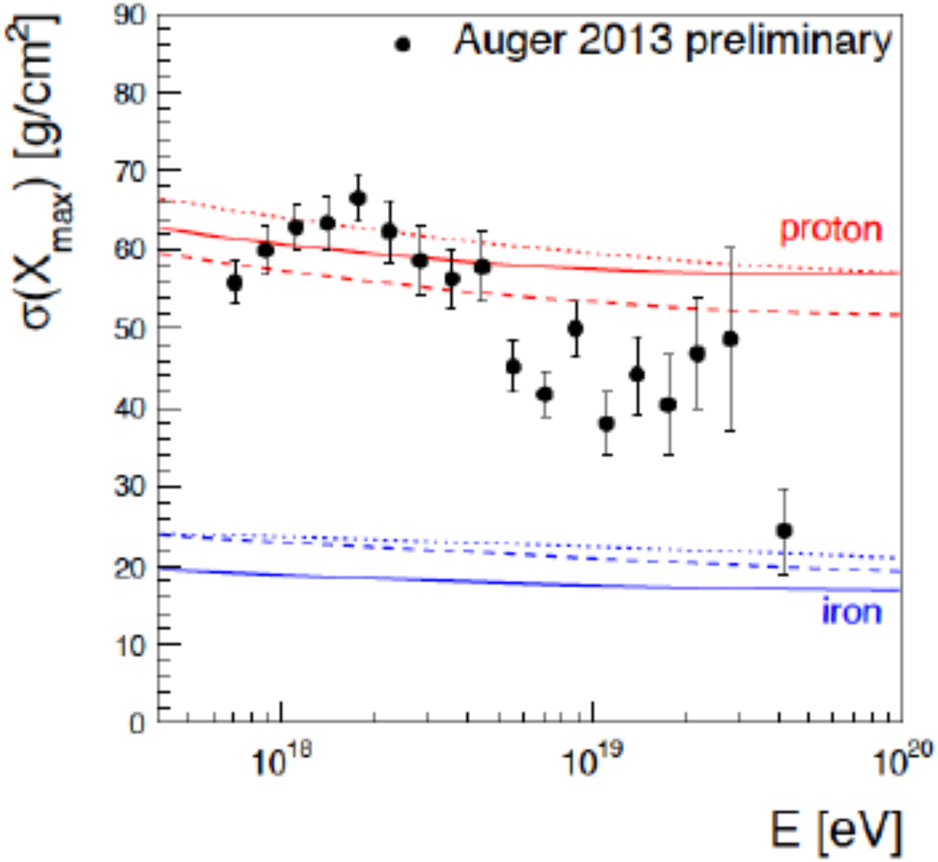


Slant depth of shower maximum (<Xmax>)
RMS of Xmax distribution at fixed energy

Composition: Xmax and RMS(Xmax)



ICRC 2013

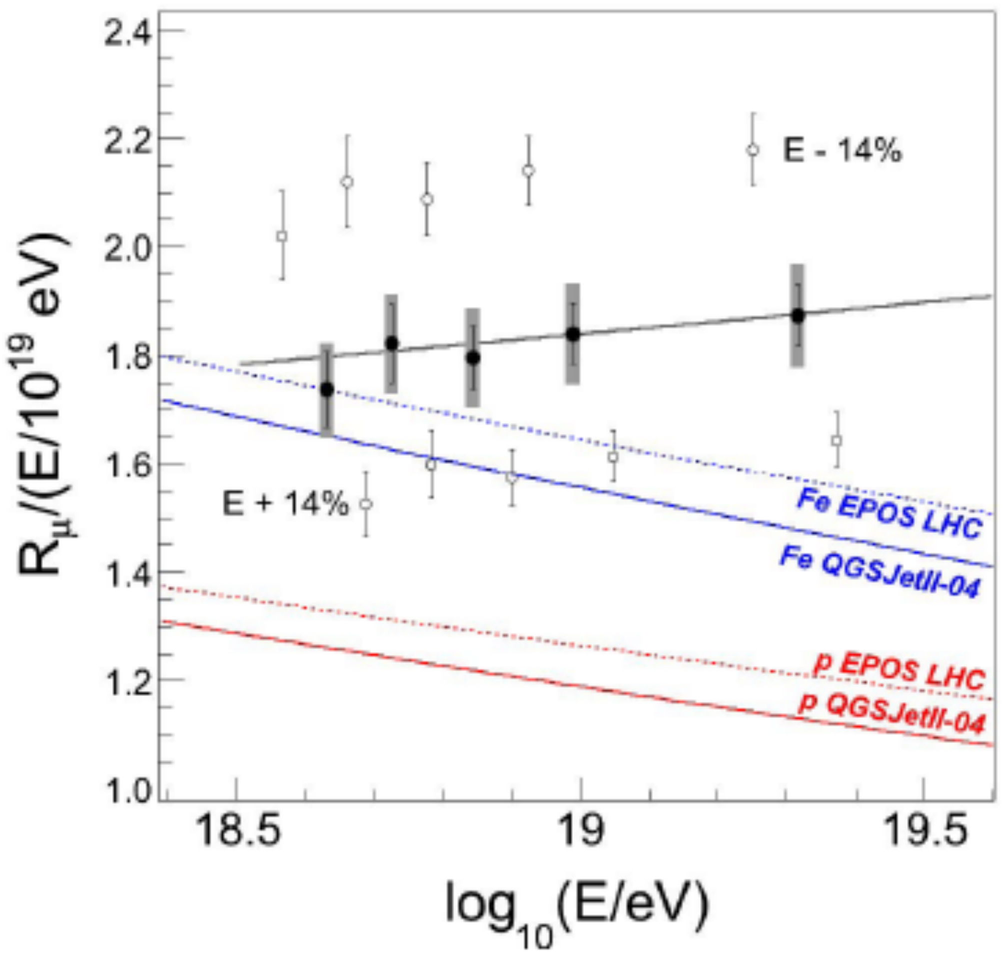


Trend to heavier composition
Pointing to sources become difficult (magnetic fields)
Are hardonic interaction models correct?

Number of muons

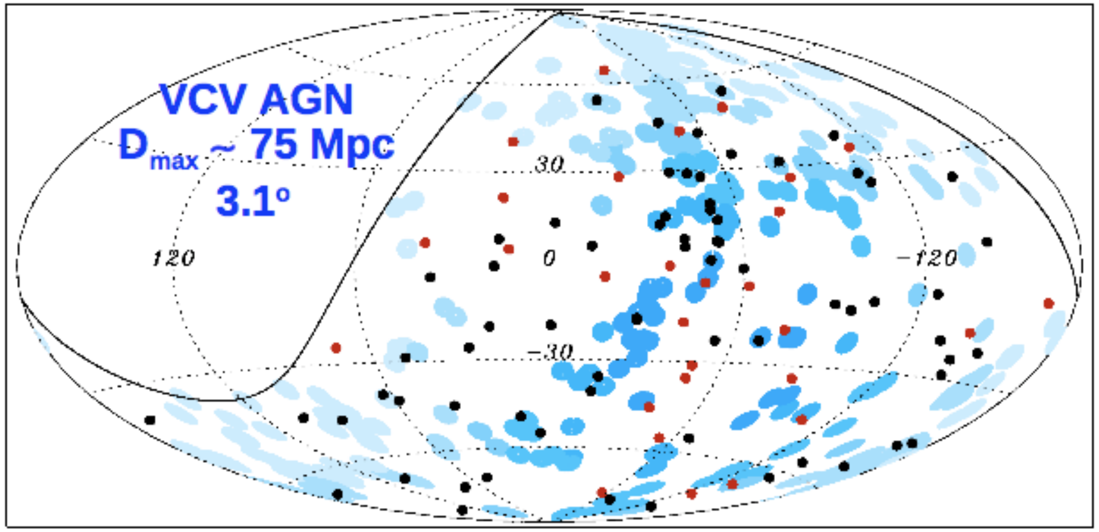
Horizontal showers: EM component completely attenuated, only muons arrive to ground.

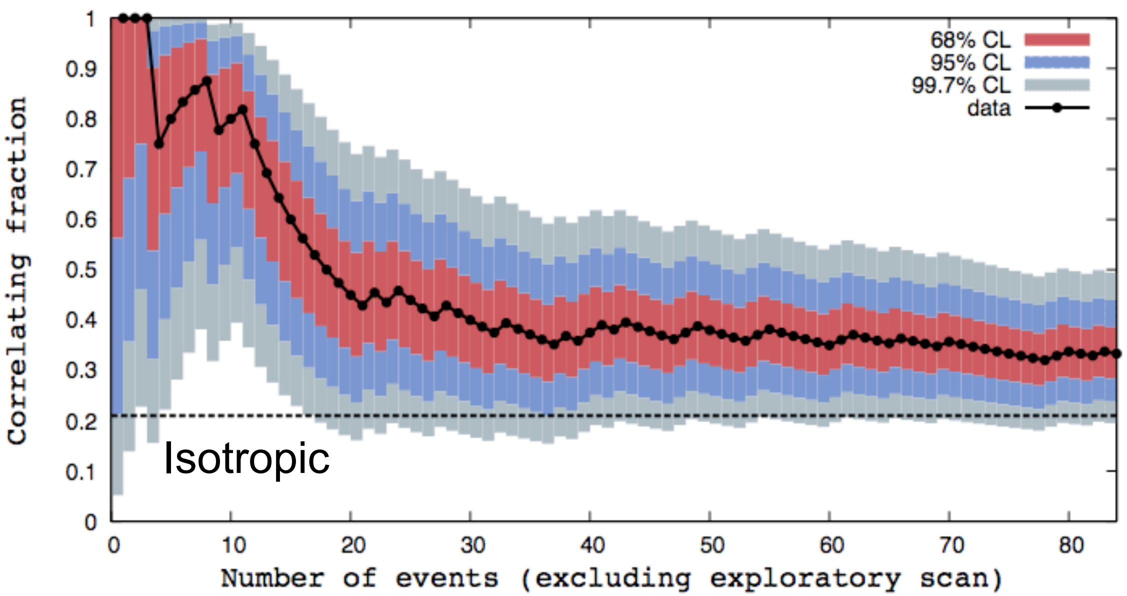
Simulations don't reproduce the muon number.



ICRC 2013

Anisotropies



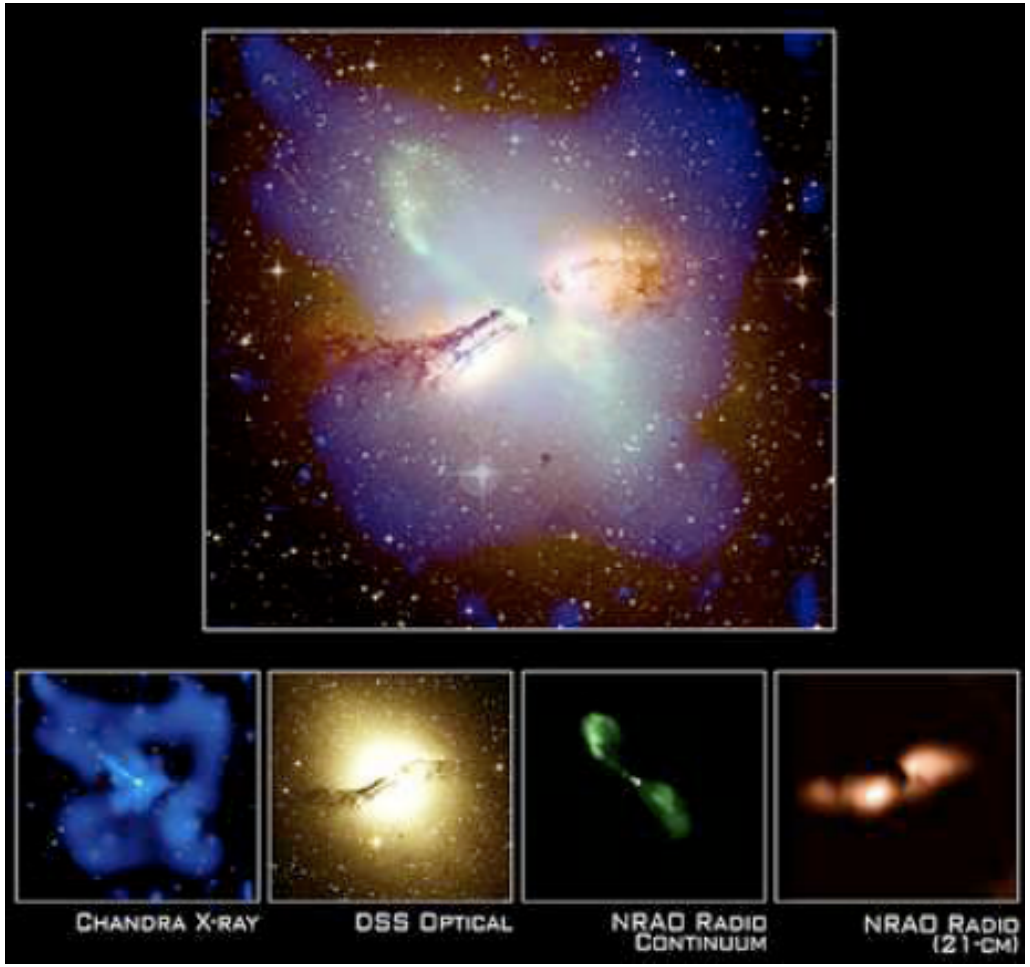


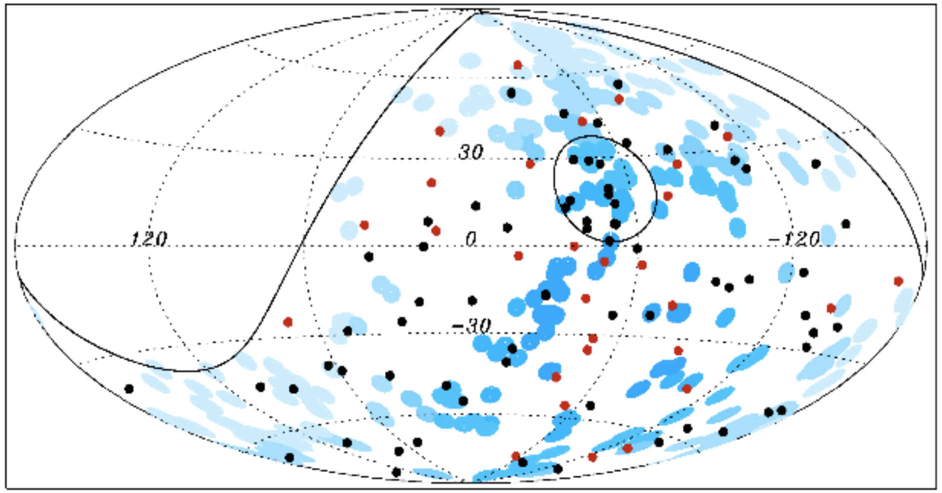
- Correlation of arrival direction with AGN catalog
- E>55 EeV, 3.1°, Dmax 75 Mpc
- First published November 2007, Science
- AGN correlation is now weaker than first indicated but is still present
- Problem: catalogs are not complete

31% of events correlate

ICRC 2013

Centaurus A

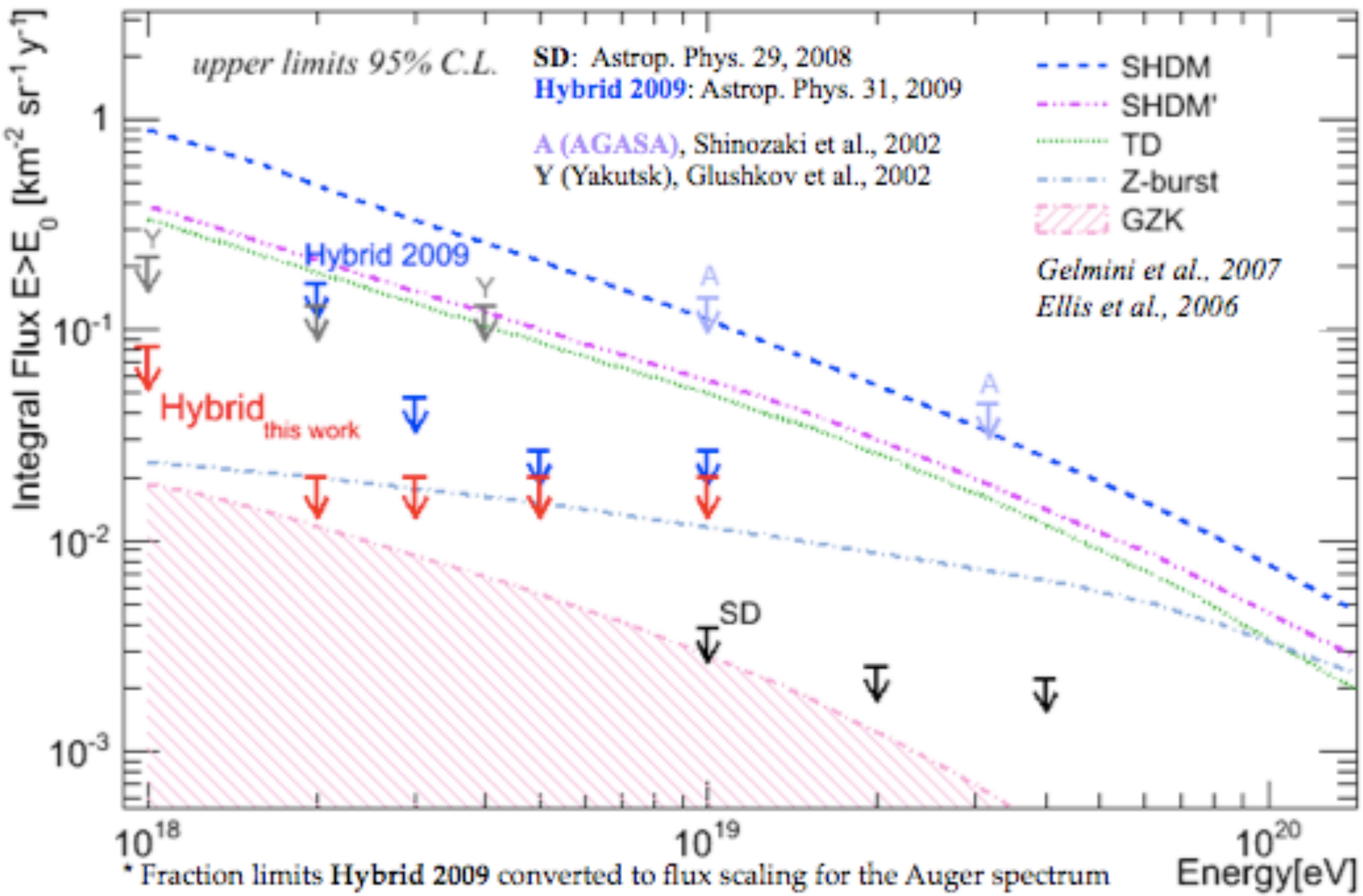




Some evidence for correlation but not confirmed

- Closest radiogalaxy (4.2 Mpc)
- Seen in all wavelengths

Photon limits



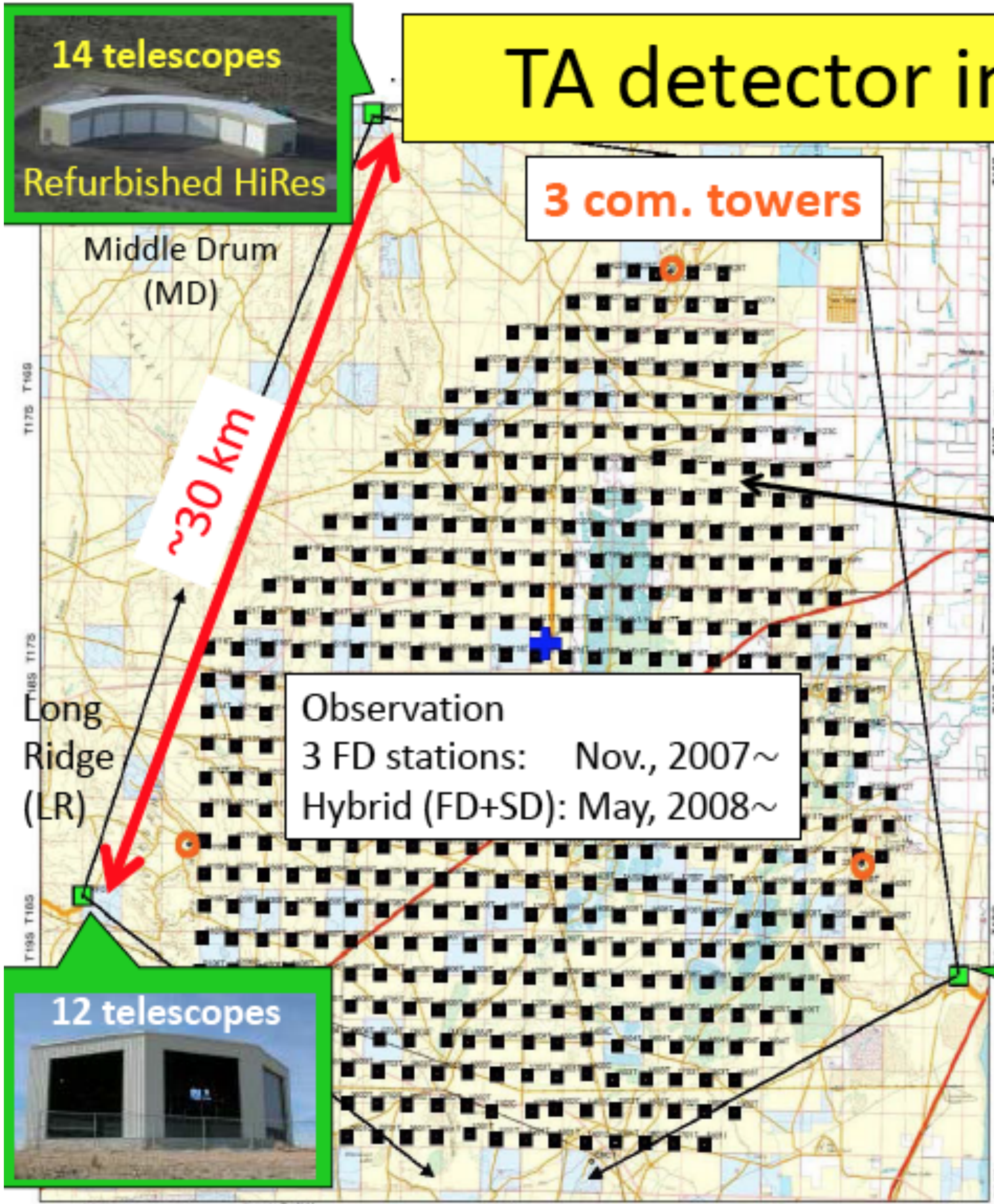
Top-down models highly constrained
GZK photons within reach

Other ground detectors

Telescope Array (TA)
The Large High Altitude Air Shower Observatory

TA detector in Utah

39.3°N, 112.9°W
~1400 m a.s.l.



Surface Detector (SD)

507 plastic scintillator SDs

1.2 km spacing

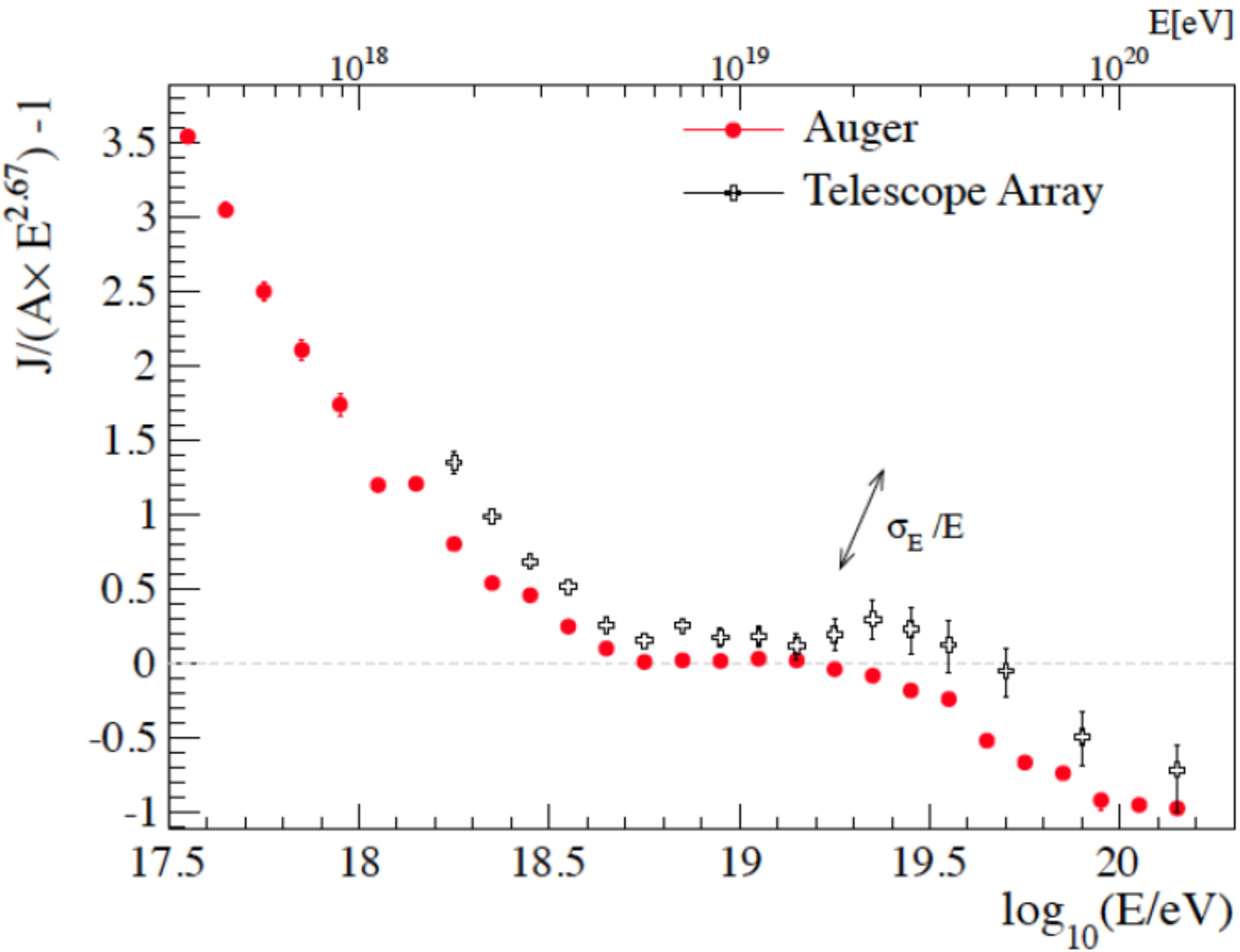
700 km^2

Fluorescence Detector(FD)

3 stations

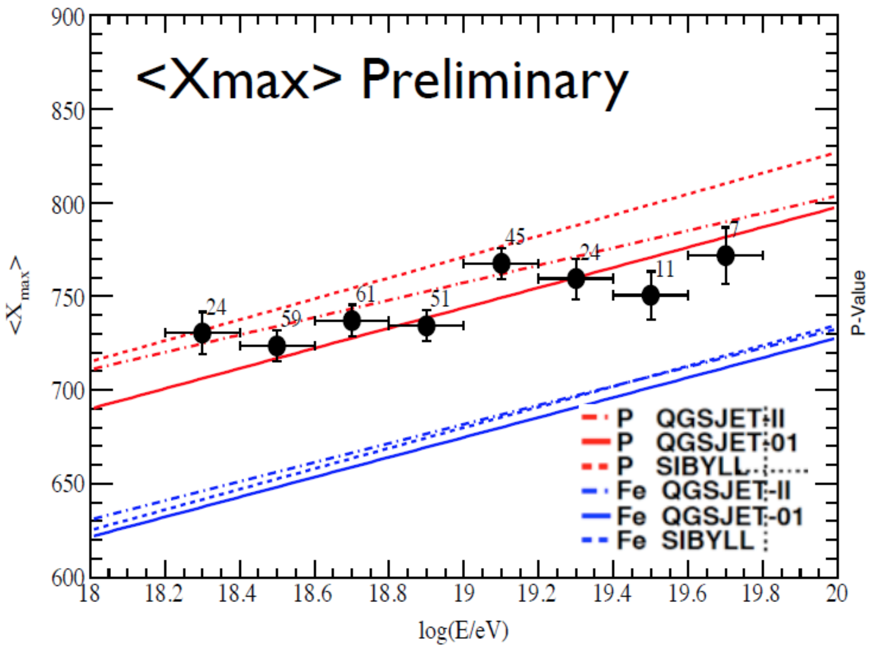
38 telescopes

Auger – TA energy spectrum



ICRC 2013

Composition and anisotropy

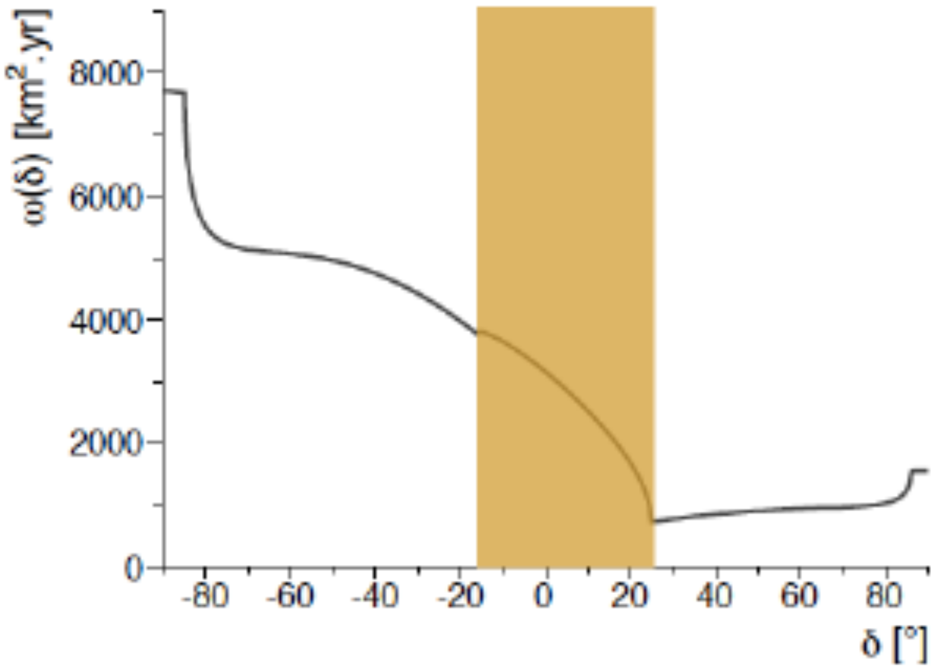


Light composition!

ICRC 2013

Auger-TA common anisotropy analysis

Common view



The Large High Altitude Air Shower Observatory LHAASO

Science case for LHAASO

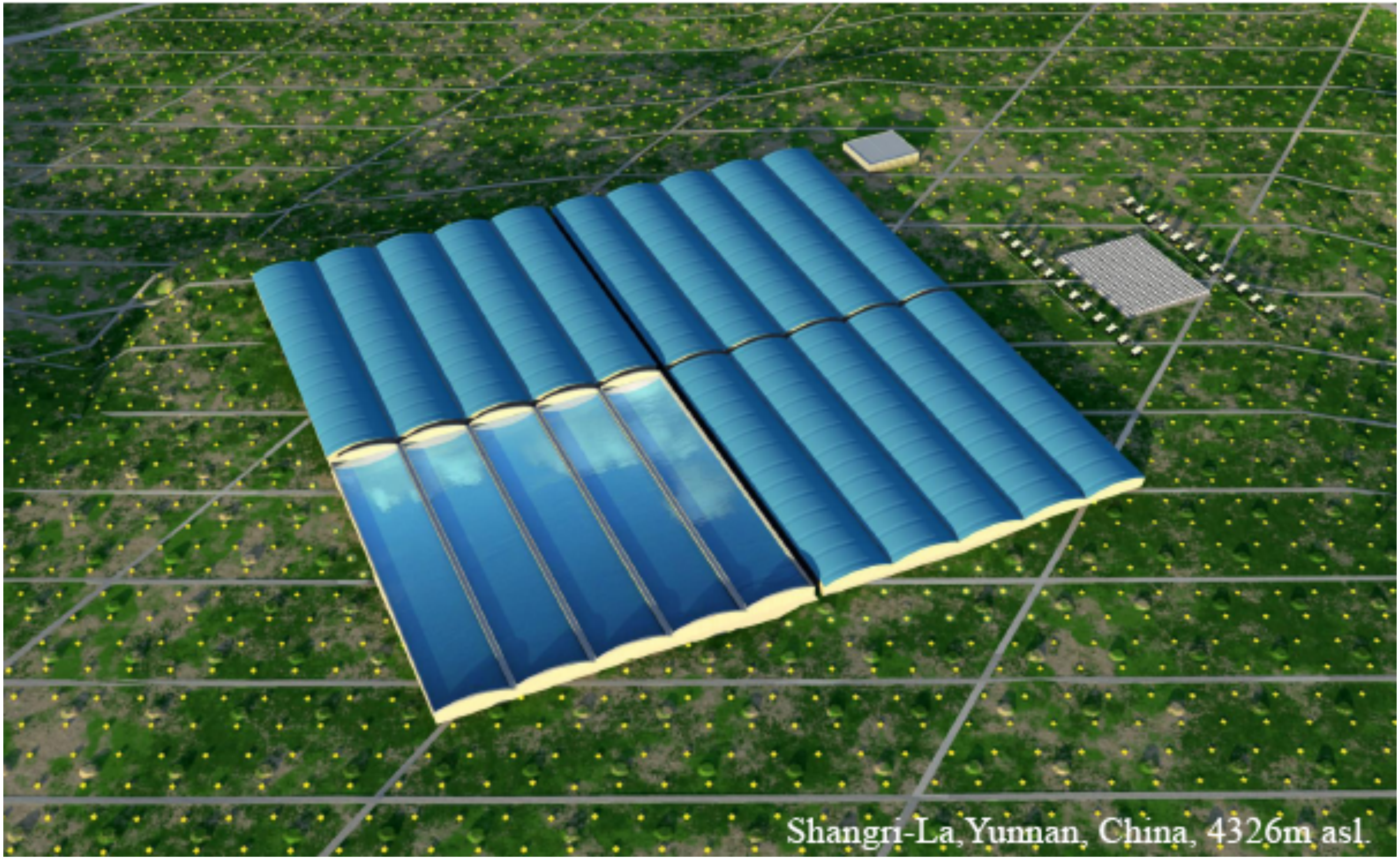
- Survey of the gamma sky above 100 GeV
  - Wide FOV and high duty cycle
  - Observation of transient sources
  - Study cosmic accelerators and high-energy phenomena
- Search for cosmic-ray origin among galactic gamma-ray sources
  - Gamma spectra at high energies
  - Visibility for hadronic origin and charged particle acceleration
- Measurement of cosmic rays above 30 TeV
  - Bridge between direct and indirect measurements
  - Unprecedented statistics for anisotropy studies in the knee region

Experimental strategy

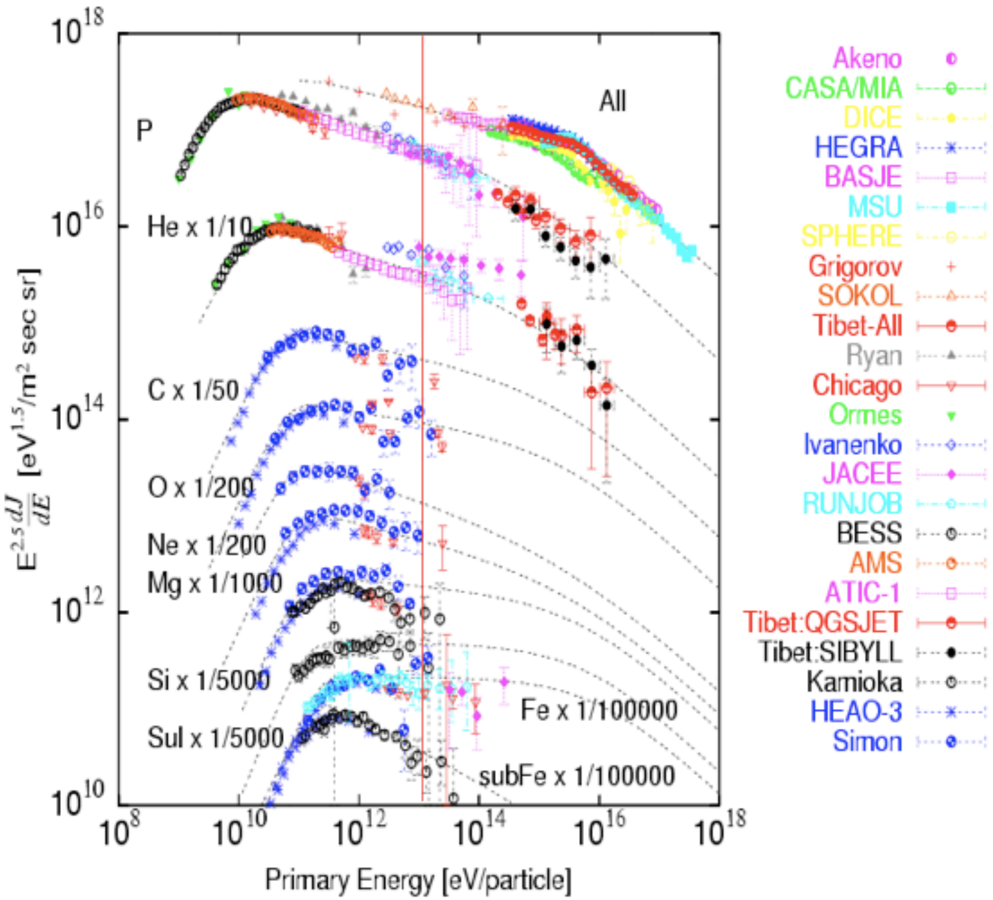
- Gamma-ray source survey: Water Cherenkov Detector Array (WCDA) with a total active area of 90,000m^2
- High-energy end of the gamma spectra: Particle detector array with an effective area of 1km^2 (KM2A) including an array of 1200 muon detectors (MD) with 940,000m^2 active area and an array of 5000 scintillators (ED) (allows to reject hadronic shower background).
- Cosmic-ray spectra and composition: 24 wide FOV Cherenkov telescope array (WFCA) and high threshold core detector array (SCDA) with an effective area of 5000m^2

  Accurate measurement of composition by combining information from KM2A

Large High Altitude Shower Observatory



Measurement of cosmic rays above 30 TeV

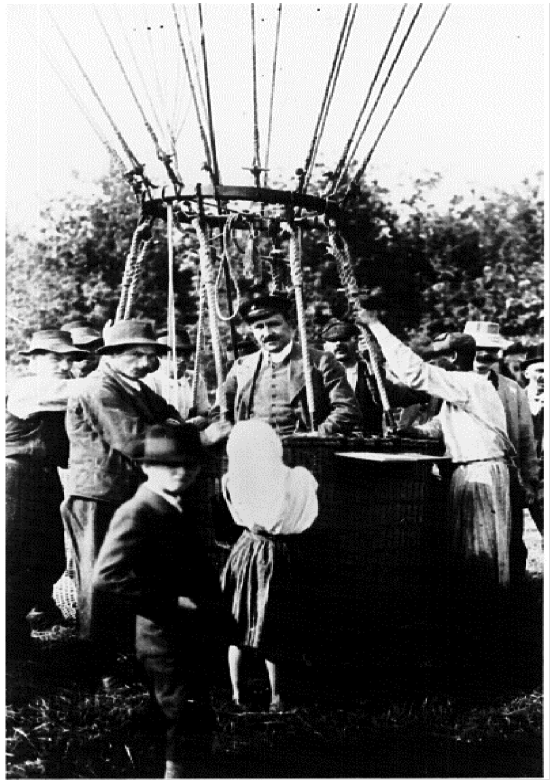


- Connection with direct measurements
- Hybrid detection with WFCTA and KM2A provides accurate measurement of composition and spectrum
- Energy spectrum and anisotropy studies for individual primary particles at the knee region

Conclusions

- Auger results so far:
  - Significant flux suppression above 5 10^{19} eV: Propagation effect or end of source power?
  - Weaker AGN correlation but interesting future targets.
  - Change in shower development with E – mass increase or hadronic interactions?
  - More muons than predicted by models: interesting particle physics?
  - Several exotic models are ruled out.
- Future plans:
  - Increase composition sensitivity: Auger Upgrade
  - Combined analysis Auger-TA
  - Lower energies are still interesting!

Cosmic rays celebrated 100 years in 2012!
But their origin is still a mystery!



Victor Hess 1912

References

ICRC 2013, Rio de Janeiro, Brasil, 1-9 July 2013