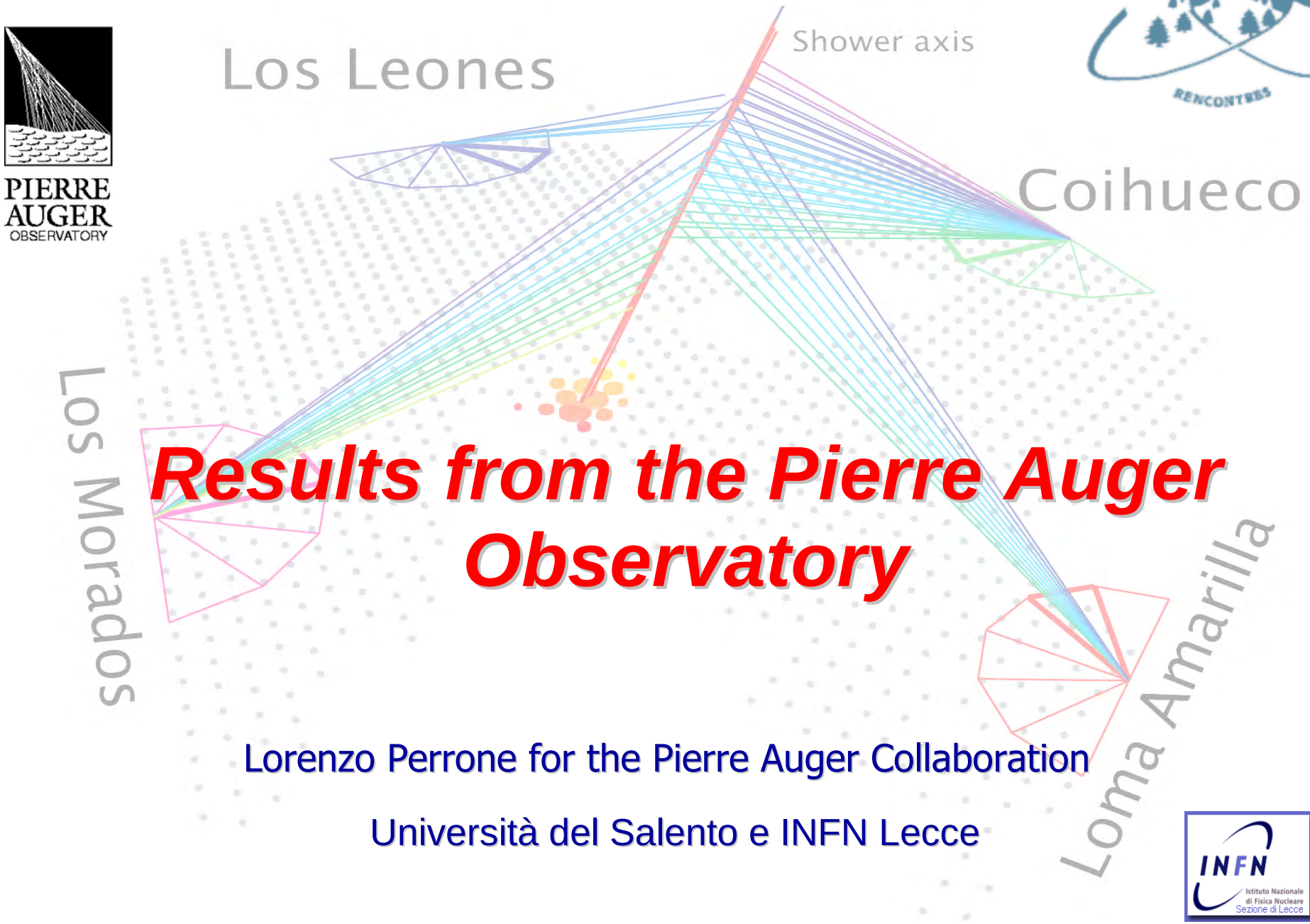
Rencontres de Moriond EW La Thuile 7-14 March 2009



Results from the Pierre Auger Observatory

Lorenzo Perrone for the Pierre Auger Collaboration

Università del Salento e INFN Lecce

Outline

- Physics goals and operation range
- Detector description
  - Performance and observables
- Results
- Enhancements and future plans

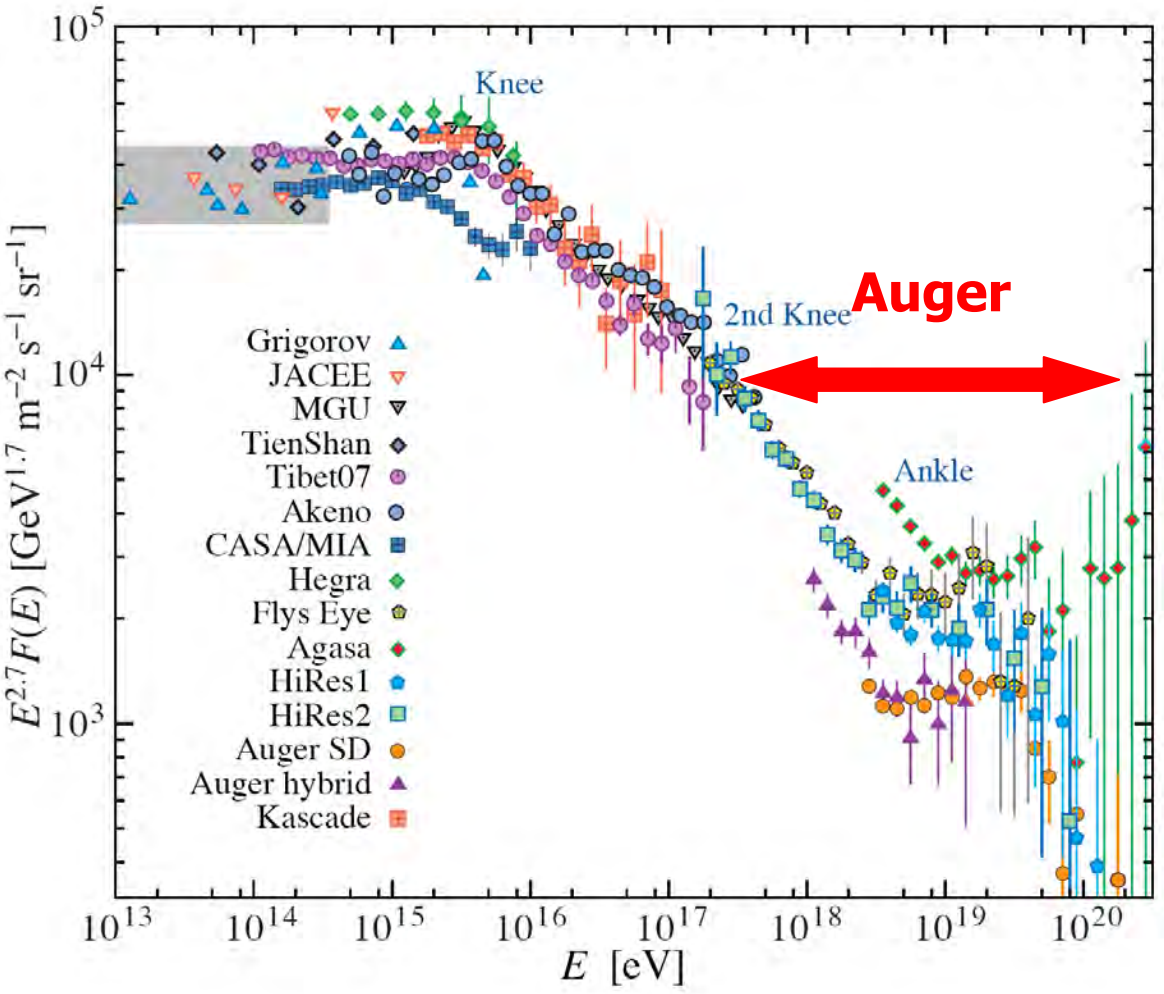
The Pierre Auger Observatory: range of operation

High-Energy cosmic rays (10^{17}-10^{21}) eV

E>$10^{19.5}$ eV, very low flux

1 particle/(km^2 sr century)

Need for large detectors (Auger 3000 km^2)



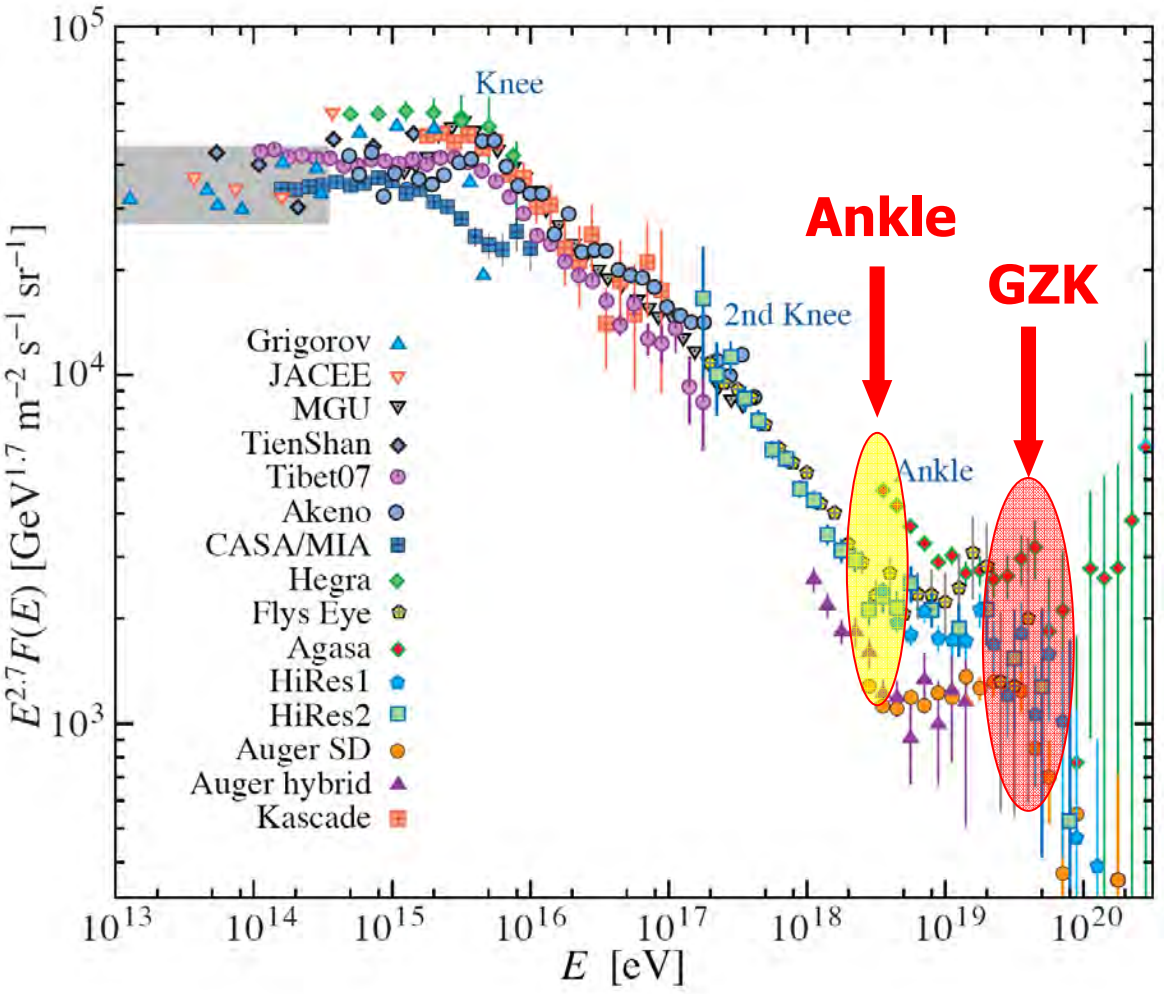
Particle Data Group 2007

The Pierre Auger Observatory: physics case

Study of the transition between galactic and extra-galactic cosmic rays (Ankle region)

End of the spectrum (GZK region)

- **Energy spectrum**
- **Arrival directions**
- **Composition**
- **Hadronic physics**
- **Search for photon and neutrinos as primary cosmic rays**

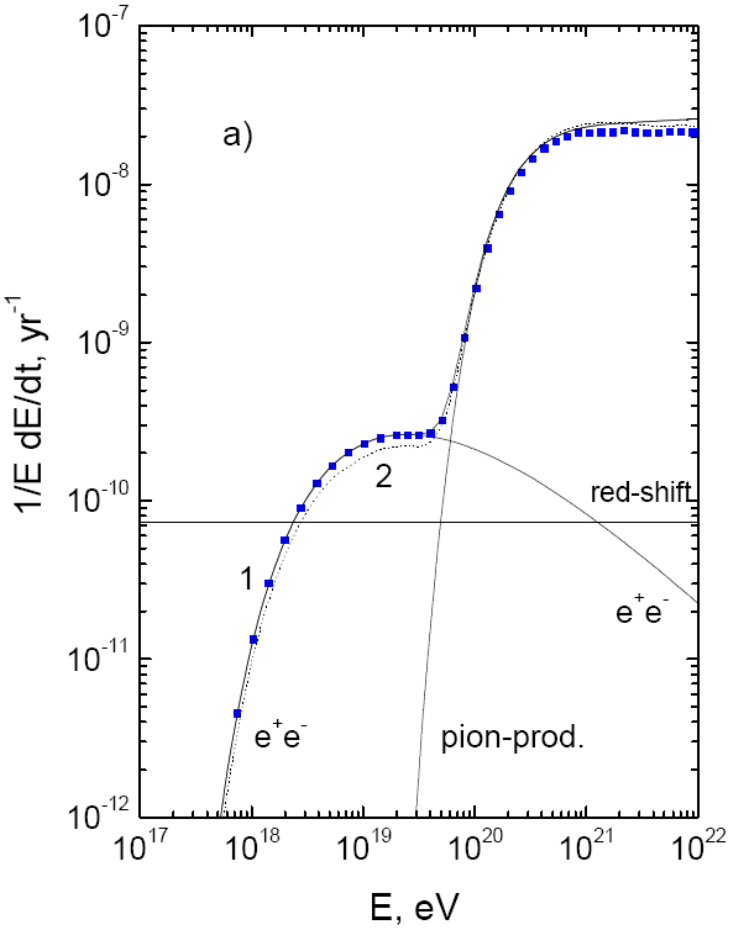


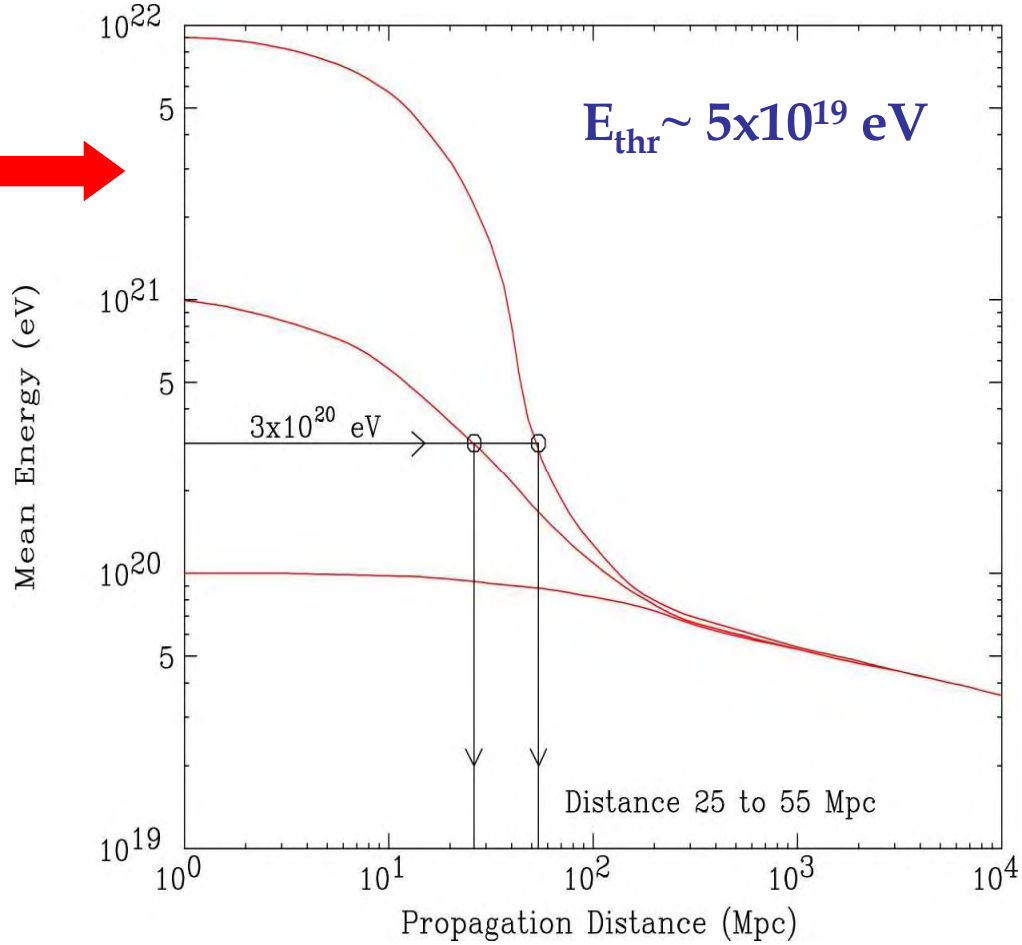
Particle Data Group 2007

Propagation of CR: implications

$$p + \gamma_{CMB} \rightarrow p + e^{+} + e^{-}$$

$$p + \gamma_{CMB} \rightarrow \Delta^{+} \rightarrow p + \pi^{0}$$



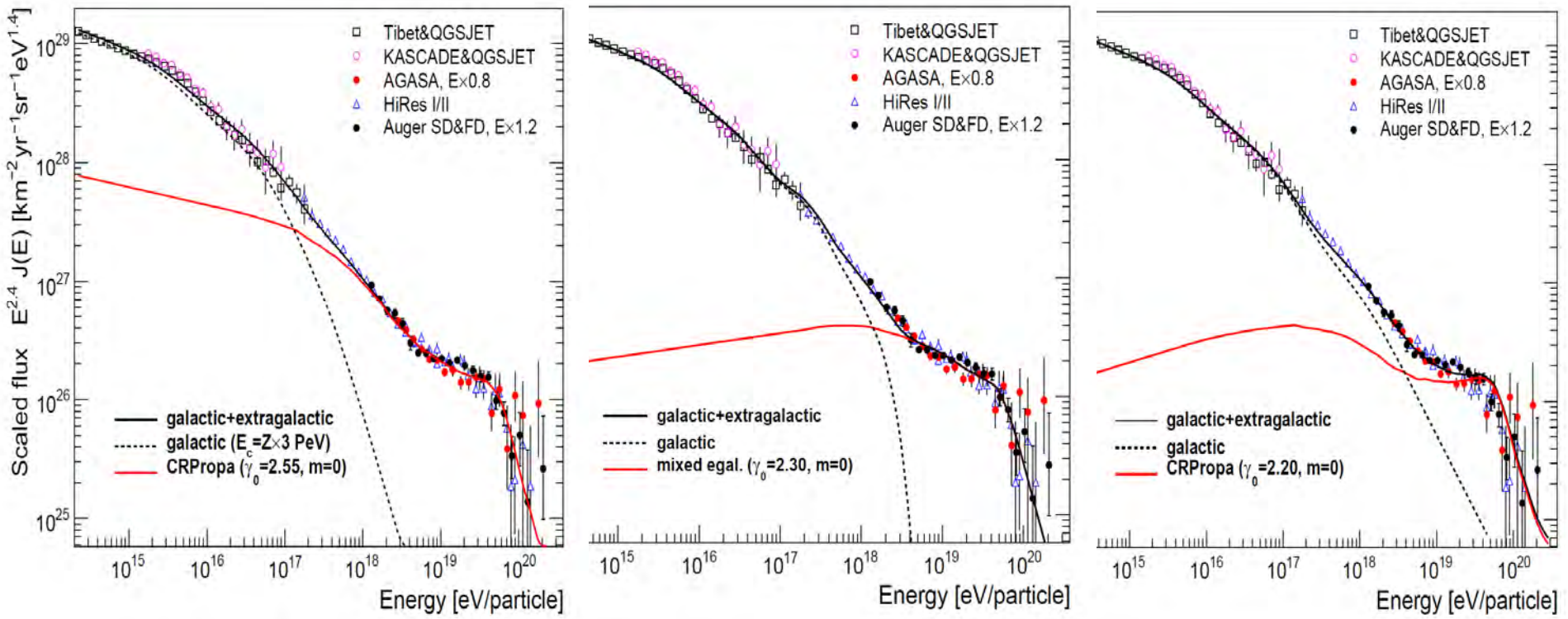


Flux Suppression (GZK cut-off)

Protons at E >10^{20} eV within 100 Mpc

Ankle: models and hyphoteses

M.Unger, arXiv:0812.2763 [astro-ph]



$E_{Gal\text{-}ExtraGal} \sim 10^{17.5}$ eV

Dip Model
Extragal. protons
(Berezinsky et al.)

$E_{Gal\text{-}ExtraGal} \sim 3\ 10^{18}$ eV

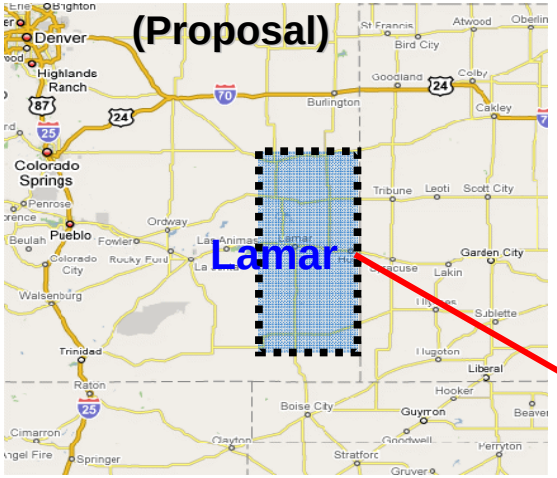
Mixed comp. of
extragal. component
(Allard et al.)

$E_{Gal\text{-}ExtraGal} \sim 10^{19}$ eV

Extragal. protons
(ankle model)

The Pierre Auger Observatory

Northern hemisphere
Colorado, USA



17 Countries
63 Institutions
~ 350 members

Southern hemisphere (3000 km²)
Malargüe (Mendoza)
Argentina

- *large and flat region*
- *low density of population (low background due to artificial light)*
- *clean and dry atmospheric conditions (small cloud coverage)*

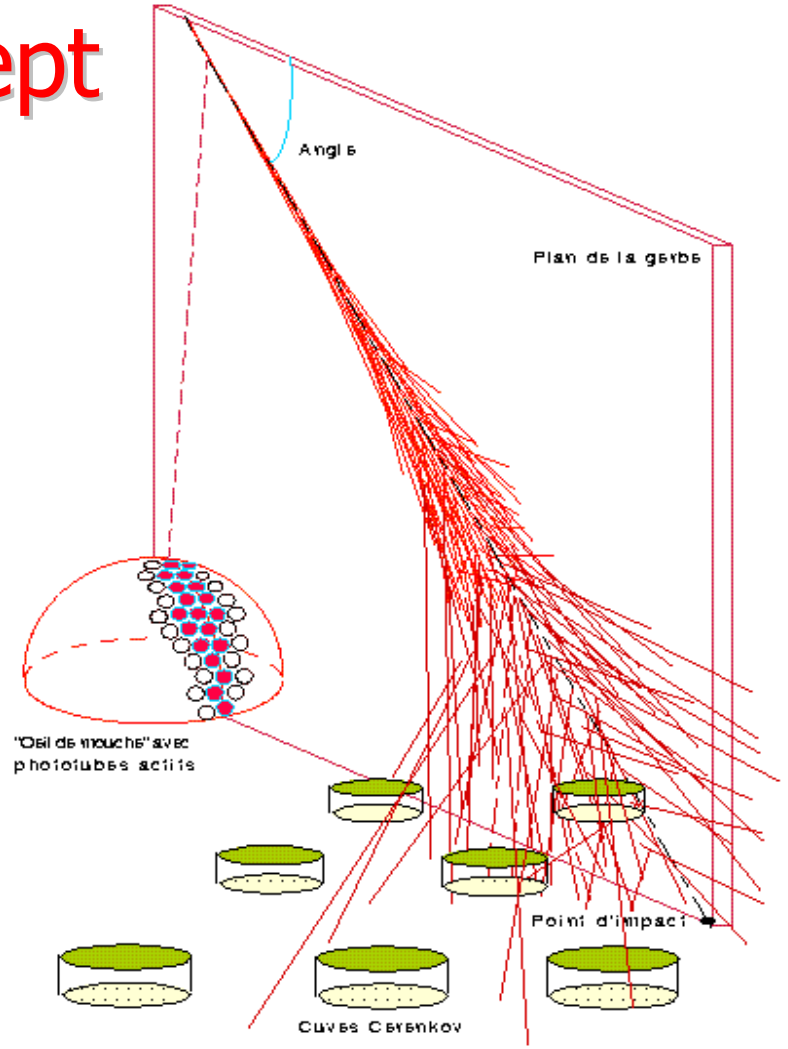
The Hybrid Concept

Surface Detector Array
lateral distribution, 100% duty cycle

Air Fluorescence Detectors
Longitudinal profile, calorimetric energy measurement, ~15% duty cycle

accurate energy and direction measurement

mass composition studies in a complementary way



"In order to make further progress, particularly in the field of cosmic rays, it will be necessary to apply all our resources and apparatus simultaneously and side-by-side."

V.H.Hess, Nobel Lecture, December 1936

The hybrid detector: layout

- ***Surface detector***

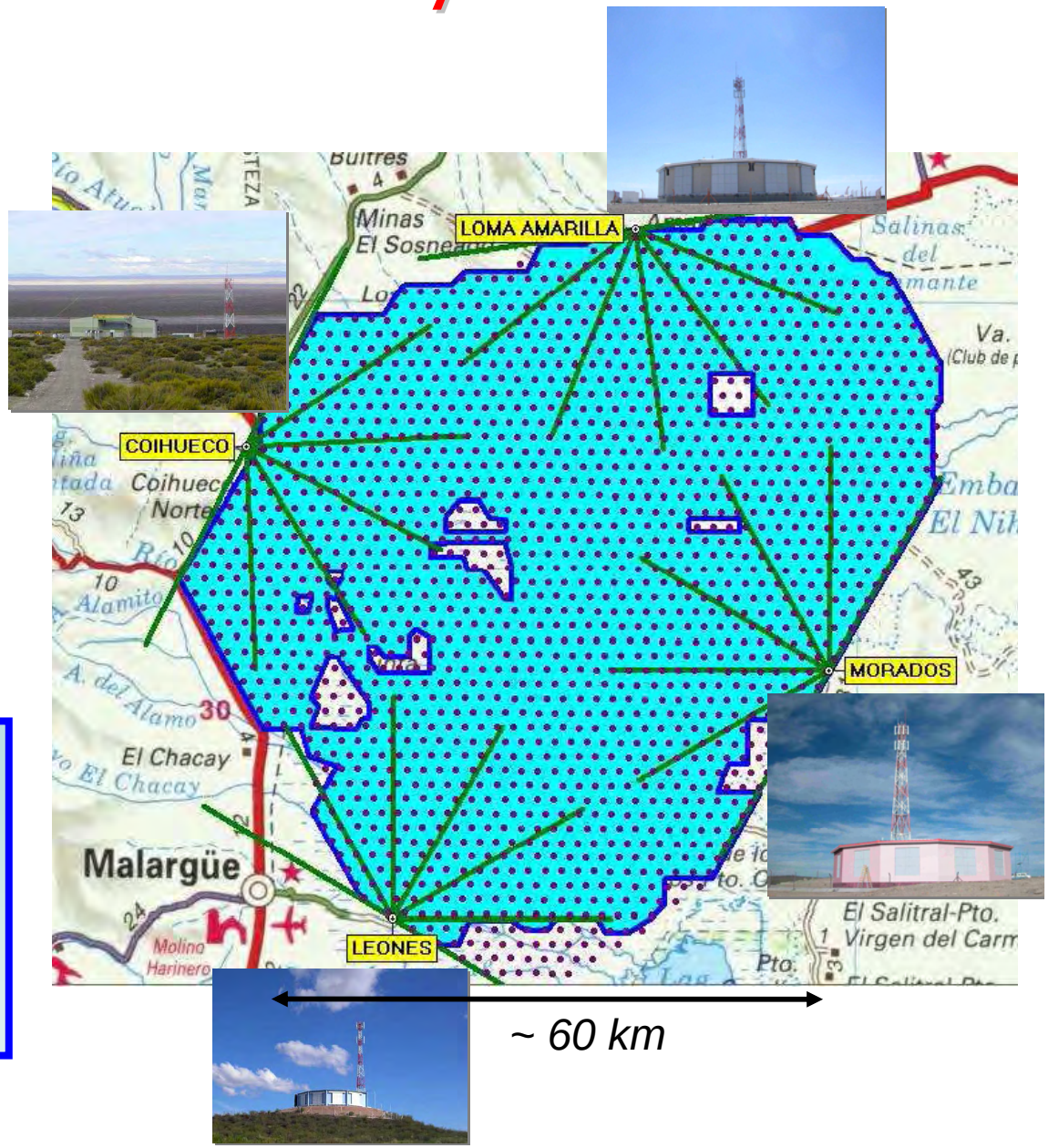
an array of 1680 Cherenkov stations on a 1.5 km hexagonal grid

- ***Fluorescence detector***

4 buildings overlooking the array

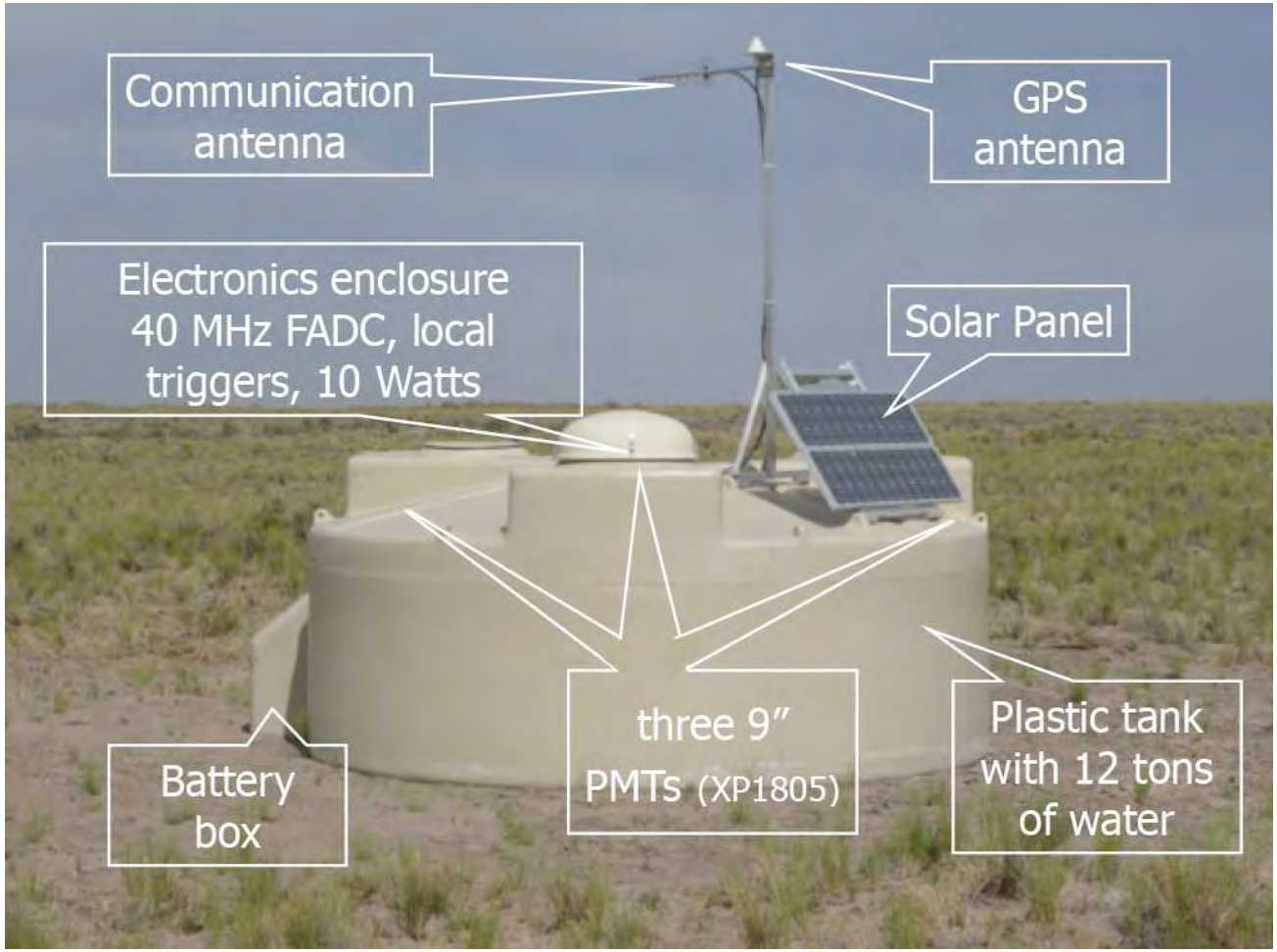
1660 deployed stations
1644 with water
1624 with electronics

All FD telescopes operative



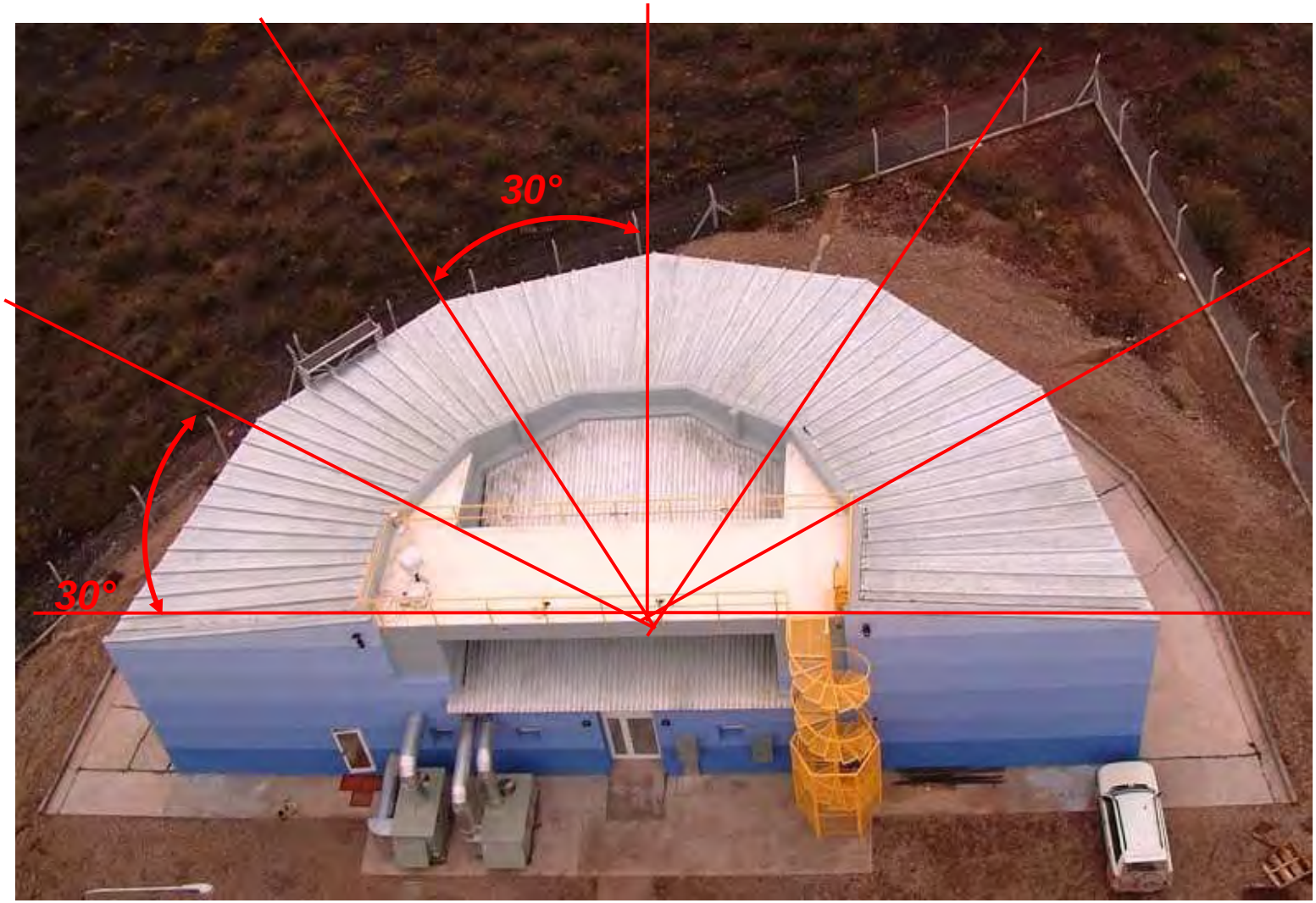
A station of the Surface Detector

- Plastic Tank
- Ultra-reflective tyvek liner
- 12 m^3 purified water
- 3 PMTs (9 inches)
- Independent power supply (solar panels)
- GPS antenna
- Communication antenna



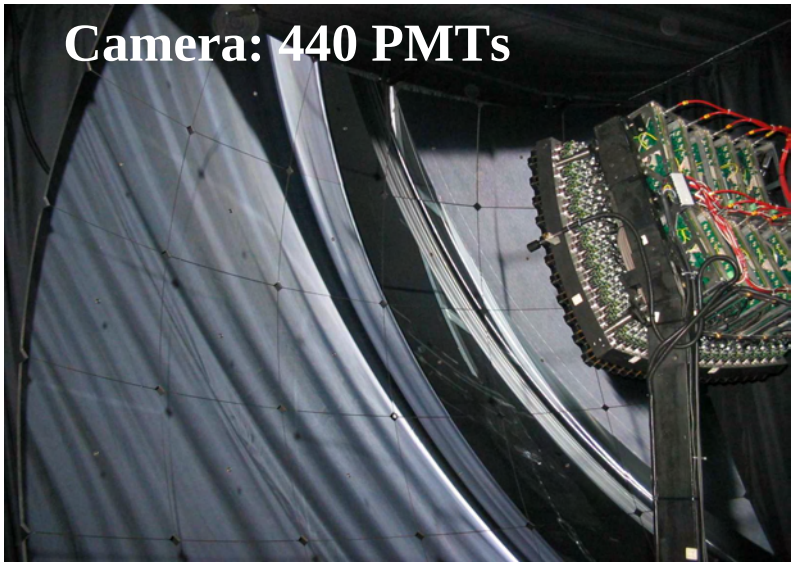
DAQ : 40 MHz FADC sampling (10 bit resolution)

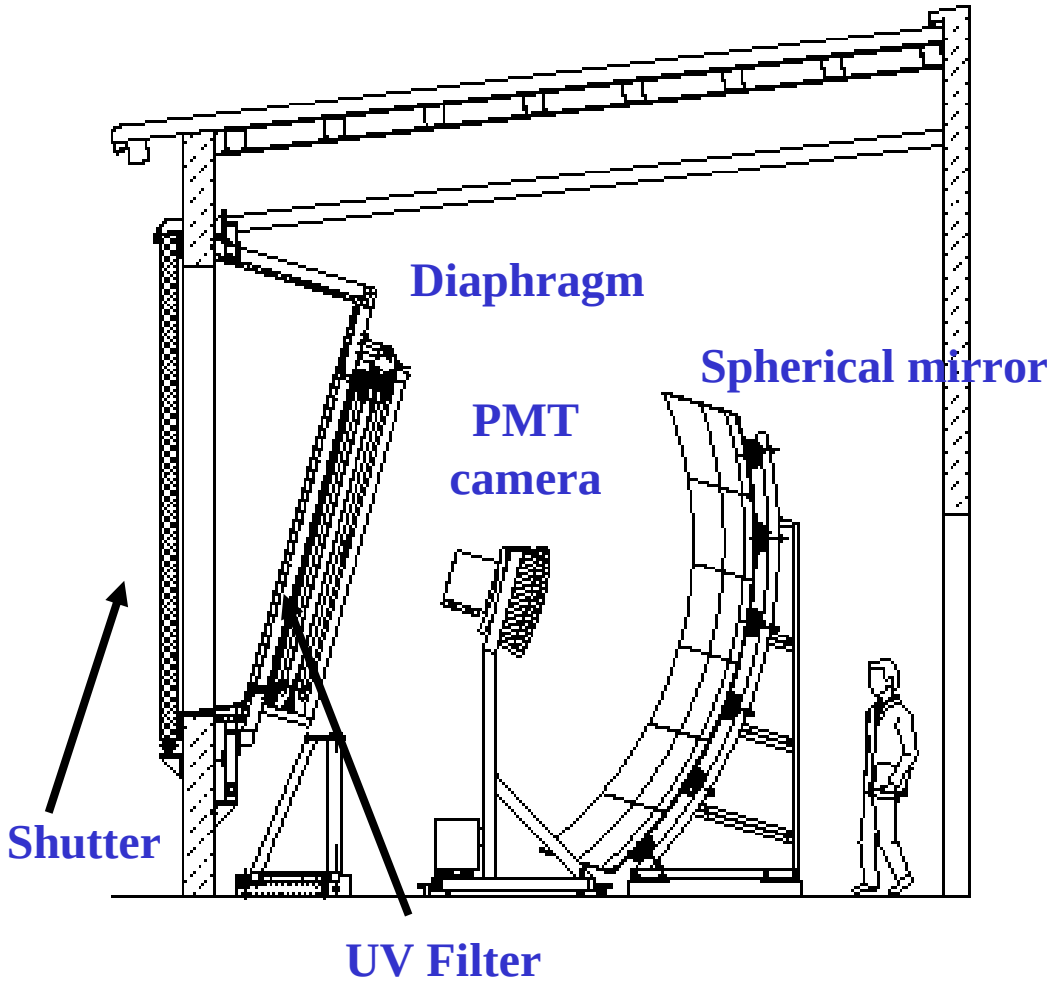
The fluorescence detector (FD)



6 telescopes, each with 30° x 30° FOV

The fluorescence detector (FD)





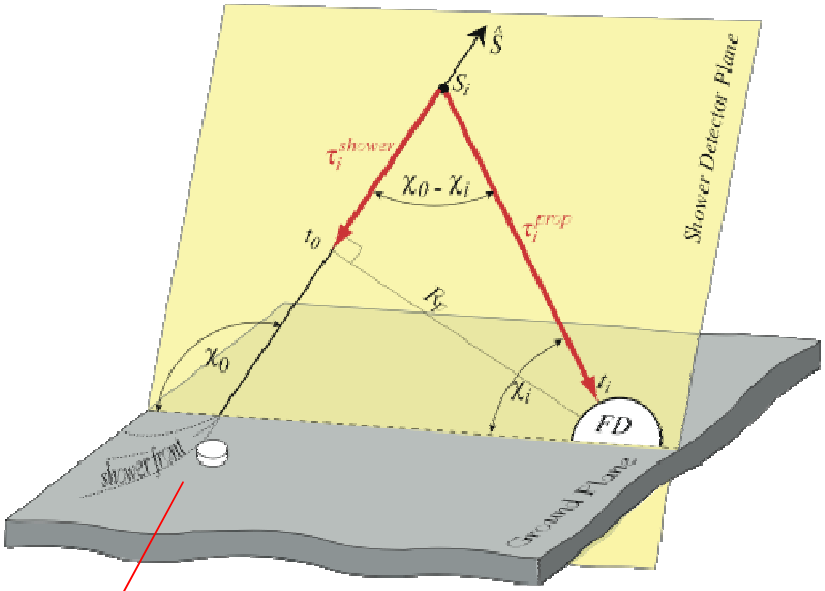
Observables and Detector Performance

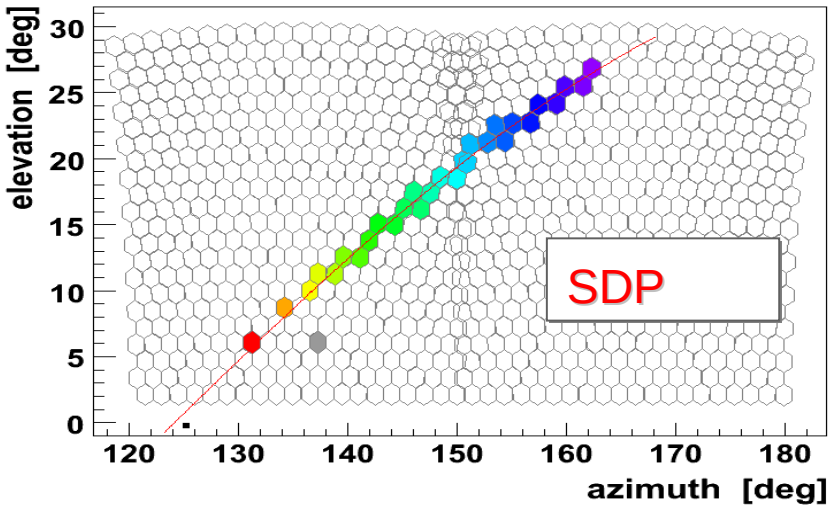
- Reconstruction of arrival directions with FD/SD/Hybrid
- Reconstruction of longitudinal profile
- Energy determination

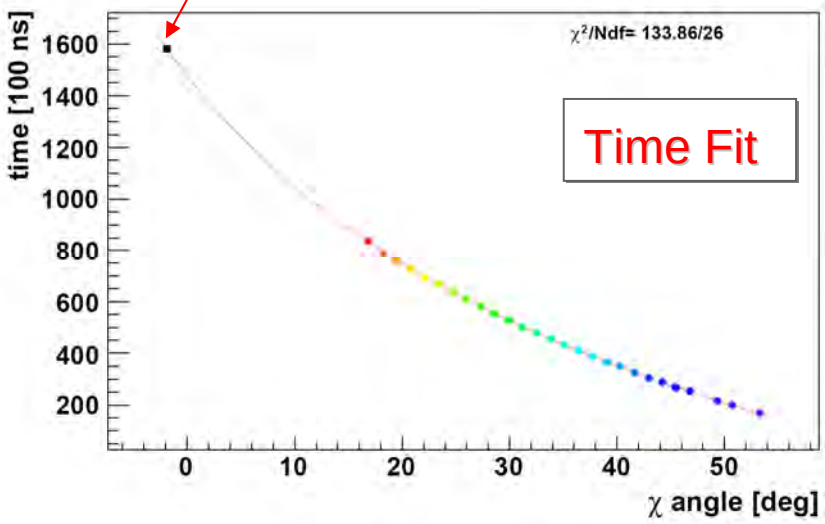
FD-Hybrid geometry reconstruction

- Shower-Detector Plane (SDP) by fitting the directions of the triggered pixels

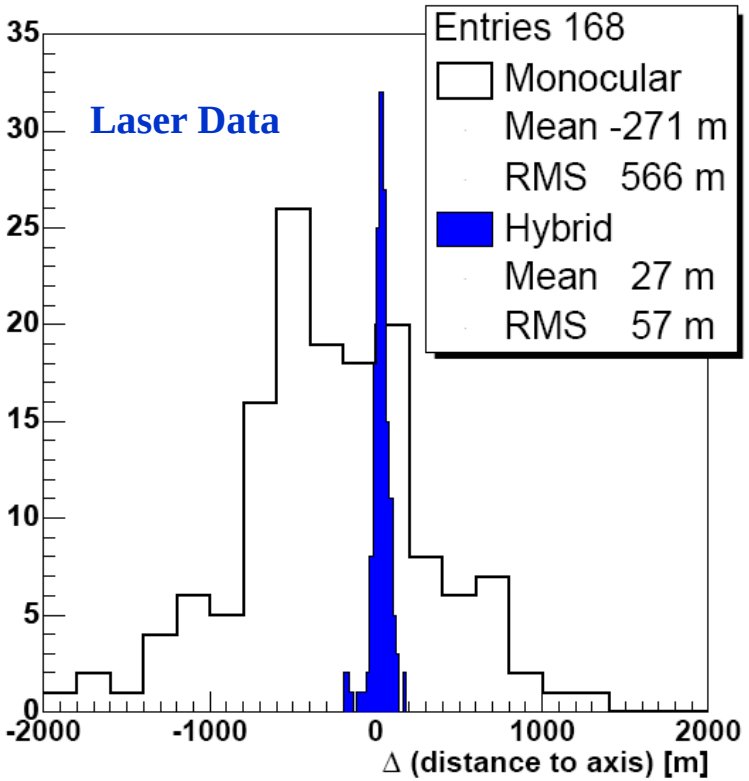
- Shower axis within the SDP, by fitting the time-sequence of triggered FD pixels using the information from the "hottest" SD tank



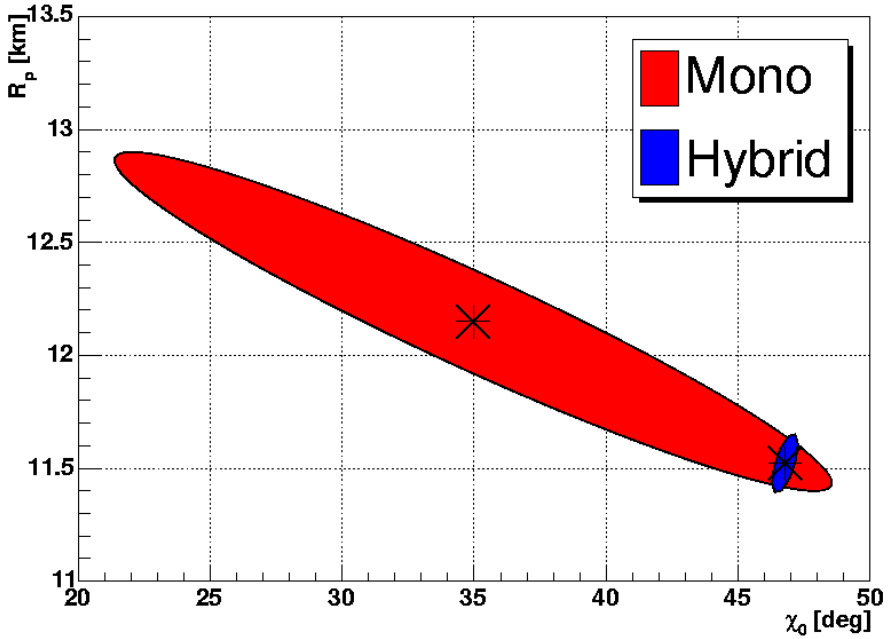




FD vs Hybrid reconstruction



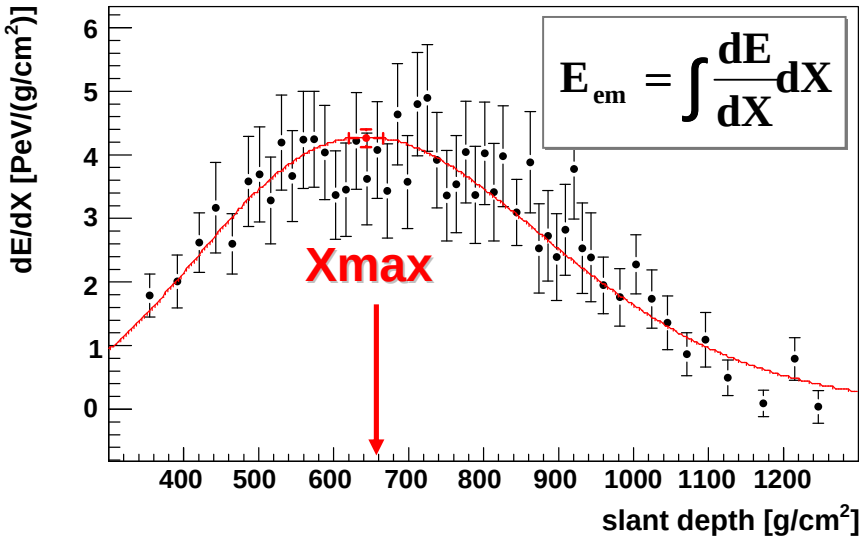
Laser position – Hybrid and FD only (m)



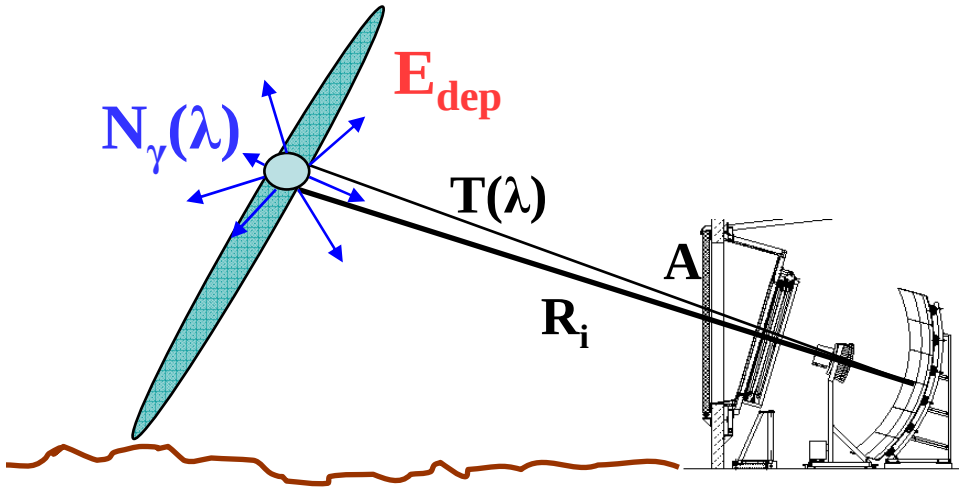
$$t_i = t_0 + \frac{R_p}{c} \tan\left(\frac{\pi - \chi_0 - \chi_i}{2}\right)$$

FD: energy determination

Longitudinal Profile



Energy "Calorimetric measurement"



E_{dep} ⇒ $N_\gamma(\lambda)$ ⇒ **Photons in FD FOV** ⇒ **Photons at diaphragm** ⇒ **ADC counts**

Fluorescence yield (from laboratory measurements)

Geometry

$$\frac{A}{R_i^2}$$

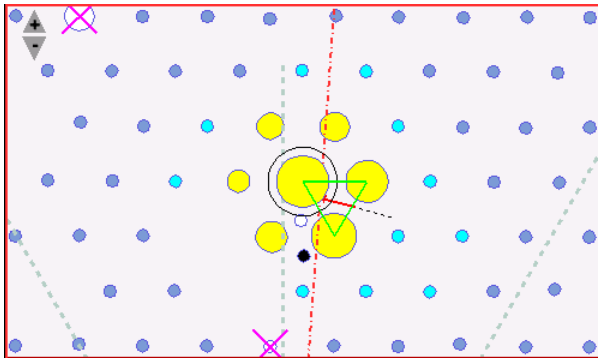
Atmosphere

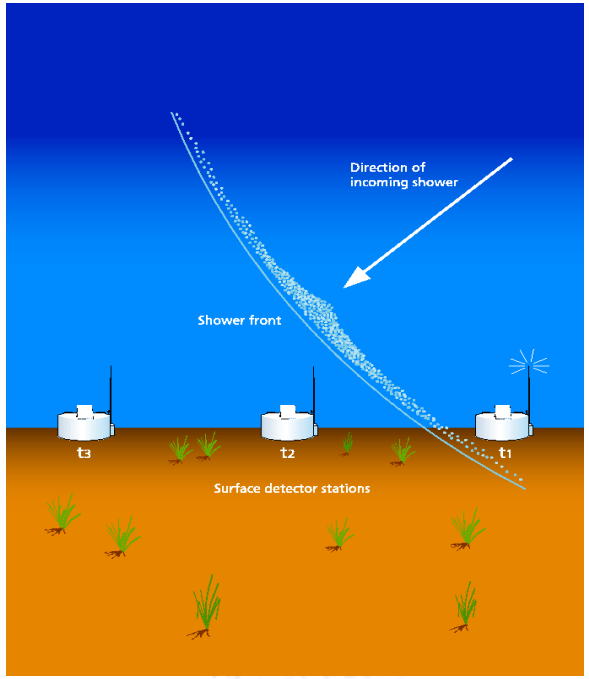
$T(\lambda)$

Detector calibration

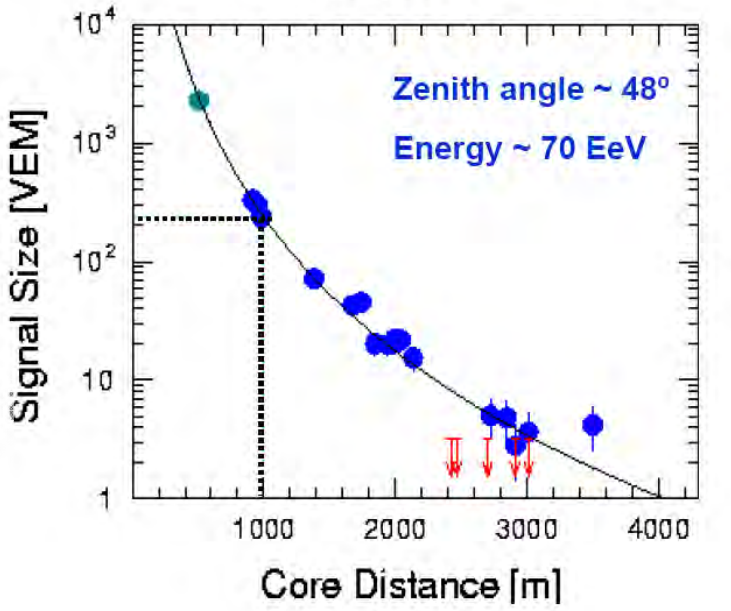
SD reconstruction

Direction:
fit to arrival times sequence of particles in shower front





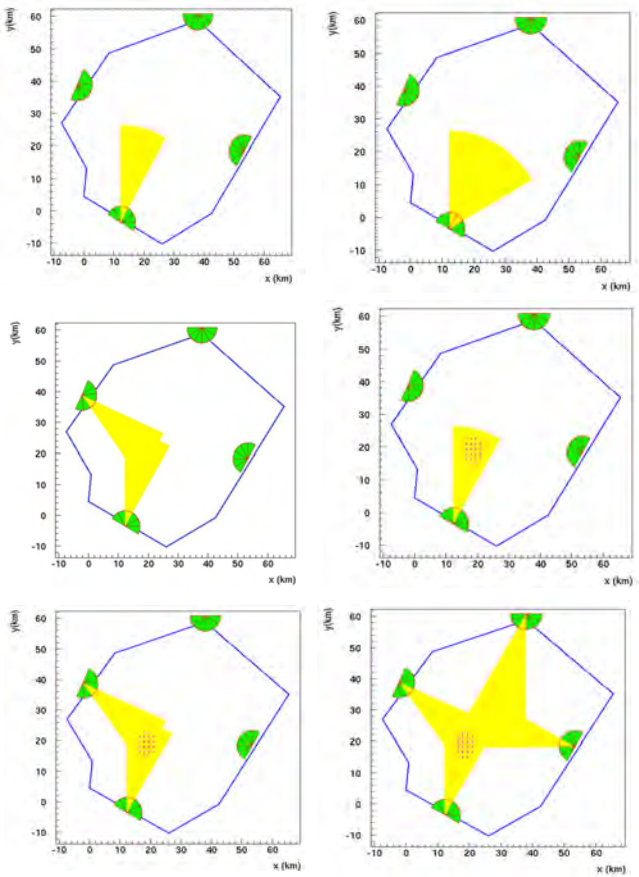
Energy estimator:
particle density at 1000 m from core S(1000)

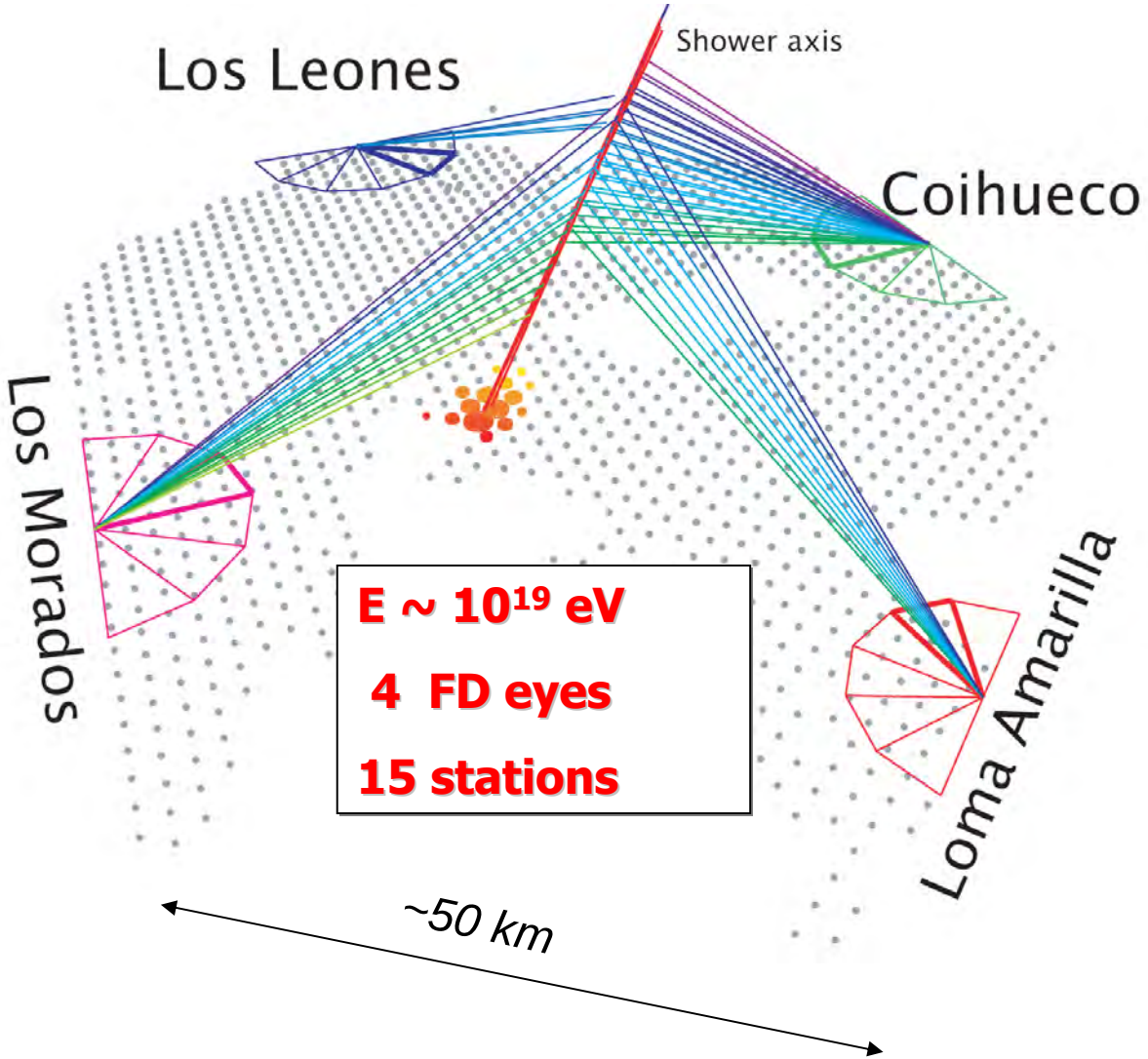


Systematic uncertainties on energy determination

- 30% from hadronic interaction models at high energy
- 10-20% from hadronic interaction model at low energy

Event topologies

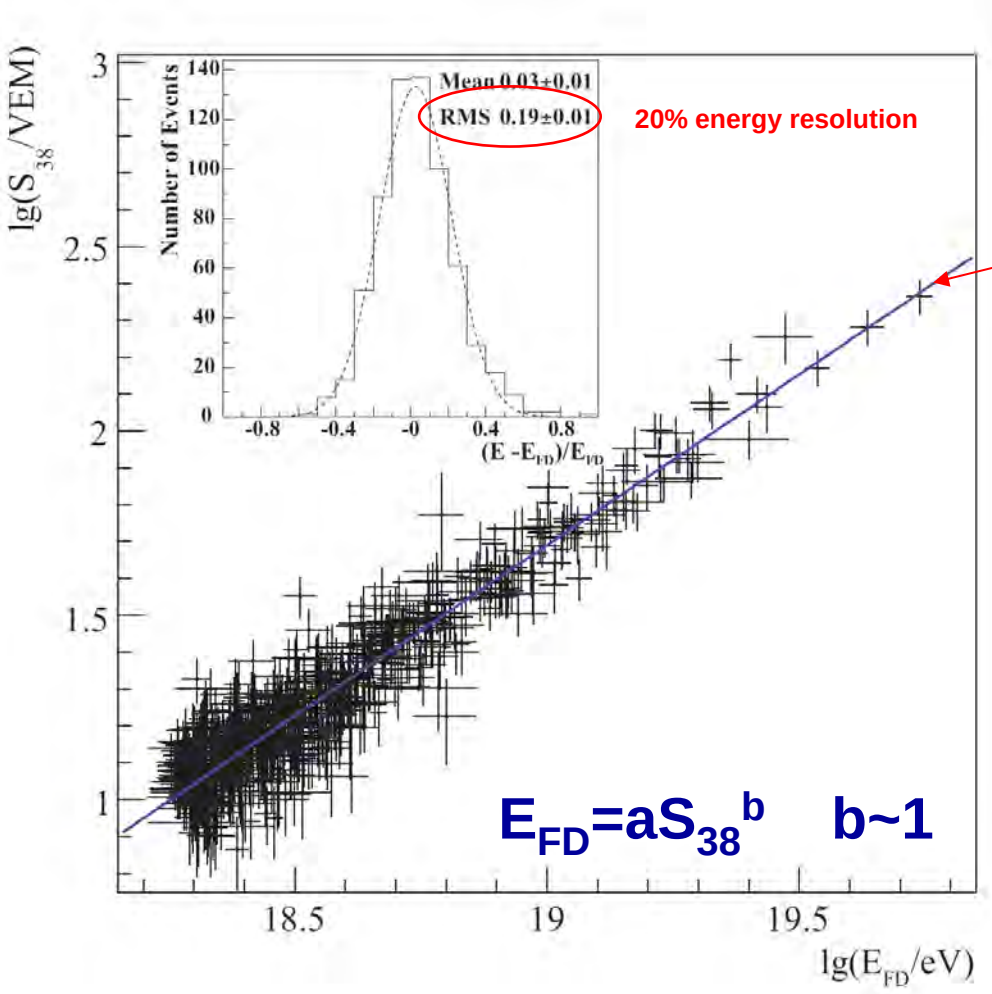




Results

- **Energy spectrum**
- Mass composition
- Astrophysics
- Search for photons and neutrinos

Energy calibration



20% energy resolution

PRL **101** 061101 (2008)

~5 10^{19} eV | **661 hybrid events**

Systematic uncertainties due to calibration procedure:

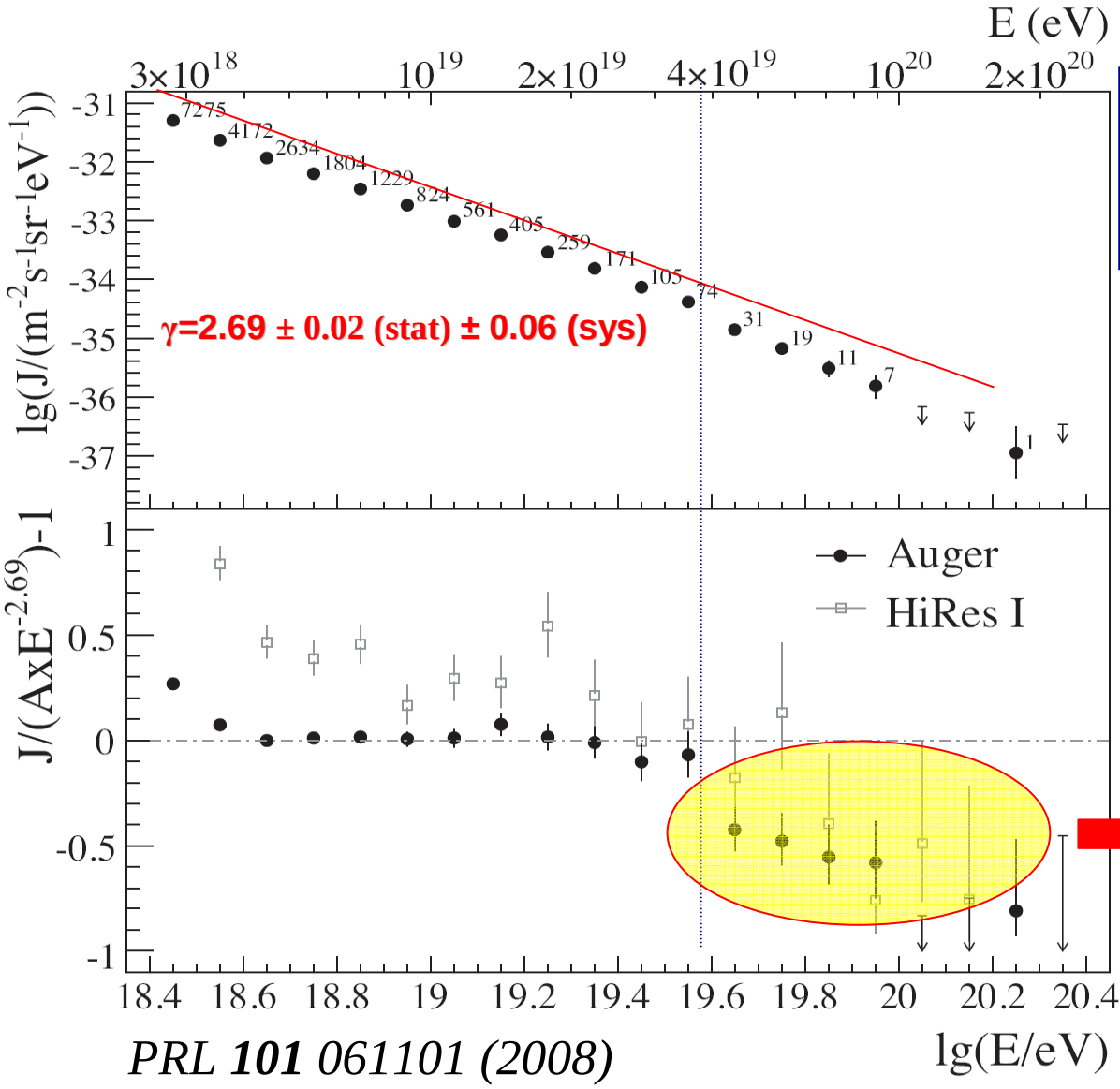
7% a 10^{19} eV

15% a 10^{20} eV

Using hybrid events, the SD energy estimator is calibrated without relying on Monte Carlo

Benefit from SD high statistics ~ 20.000 events between 1/1/2004 and 31/7/2007

Energy spectrum



*PRL **101** 061101 (2008)*

Exposure 7000 km² sr yr

Not relying on simulations

E > 10^{20} eV

1 event obs / 35 expected

E> 4 10^{19} eV

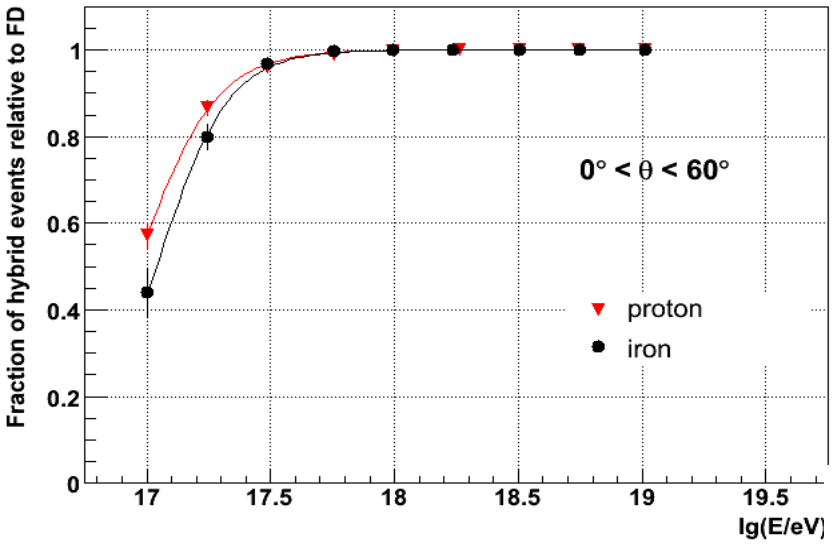
66 events obs / 167 expected

Flux suppression > 6 σ

Auger and HiRes I:

Flux compatible with a ~ 15% relative shift in the energy scale

Towards the lower energies with hybrids



Hybrid Acceptance depends on

- energy

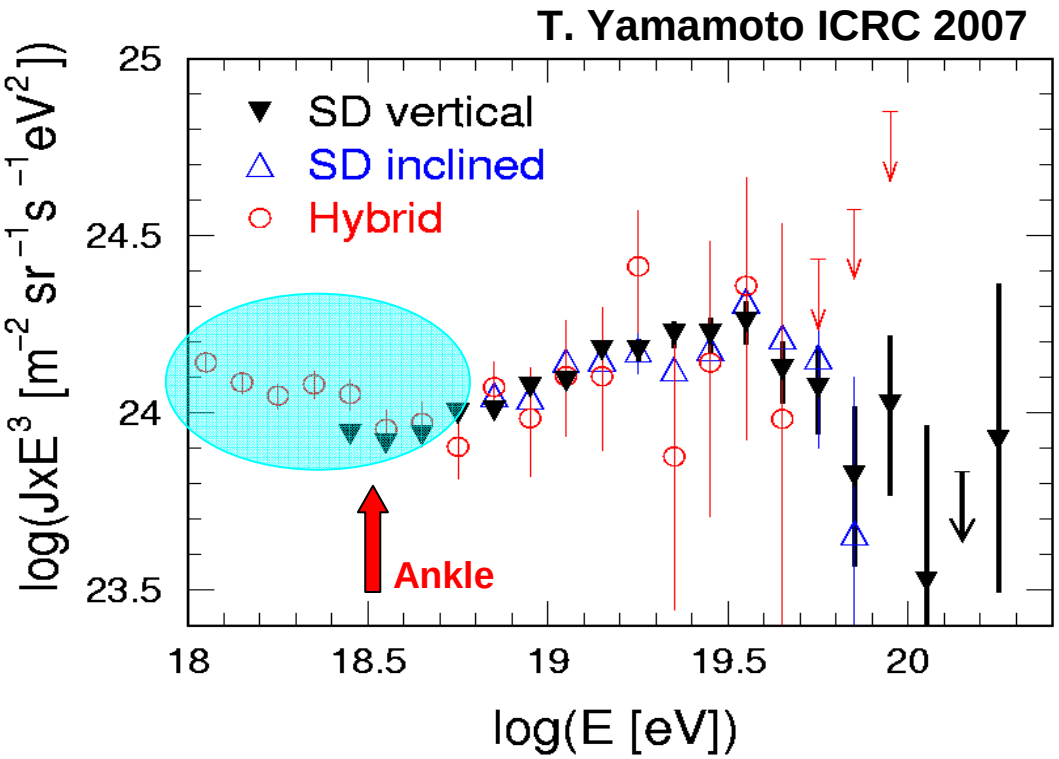
- instantaneous detector configuration

- Monte Carlo

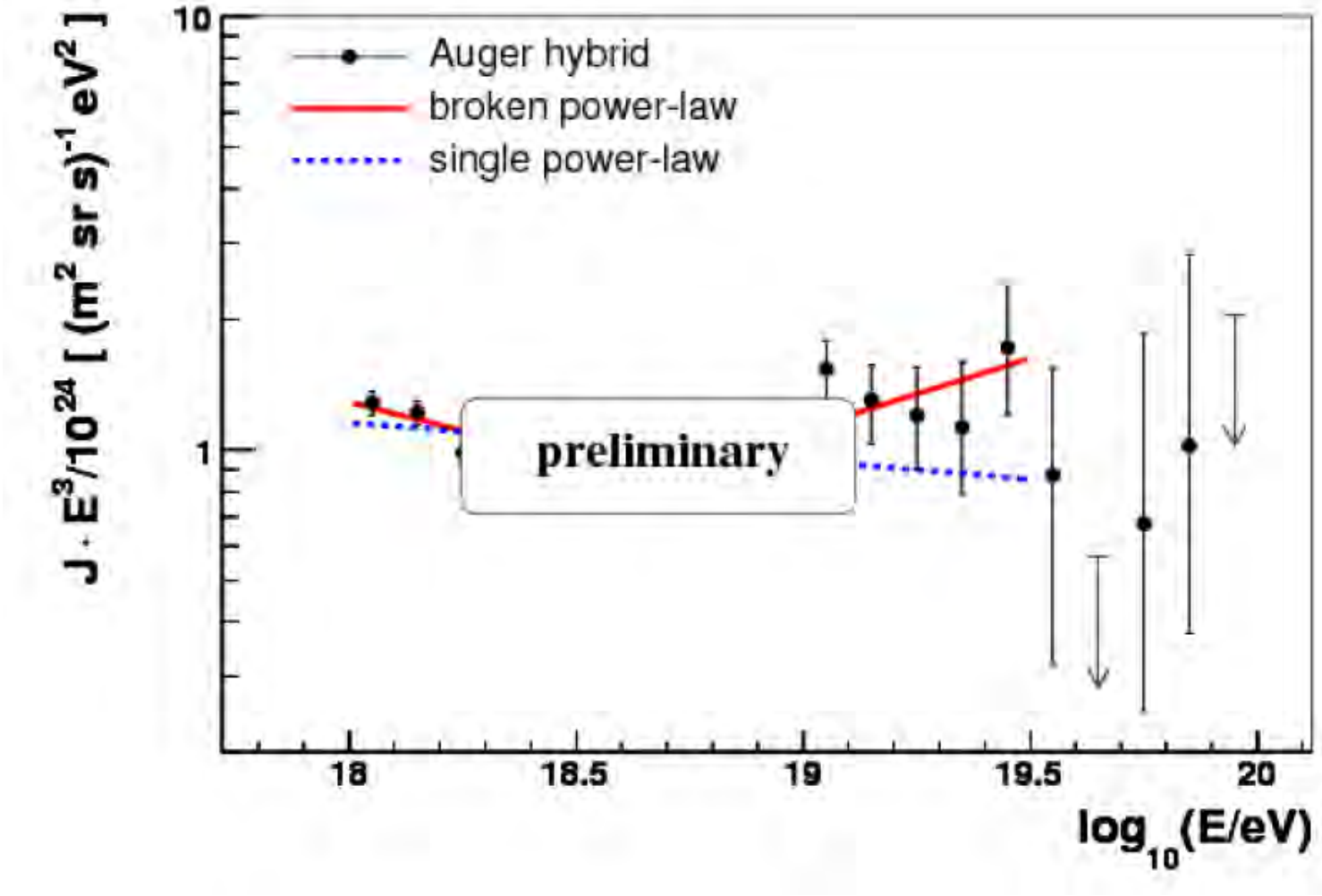
Hybrid events with at least one SD station

E > 10^{18} eV:

- *Full efficiency*
- *No dependence on mass composition*



Hints of imminent new results



F. Schuessler **44th Rencontres de Moriond,** Feb 2009

Energy scale: systematic uncertainty

Source	Systematic uncertainty
Fluorescence yield	14%
P,T and humidity effects on yield	7%
Calibration	9.5%
Atmosphere	4%
Reconstruction	10%
Invisible energy	4%
TOTAL	22%

Nagano + Airfly

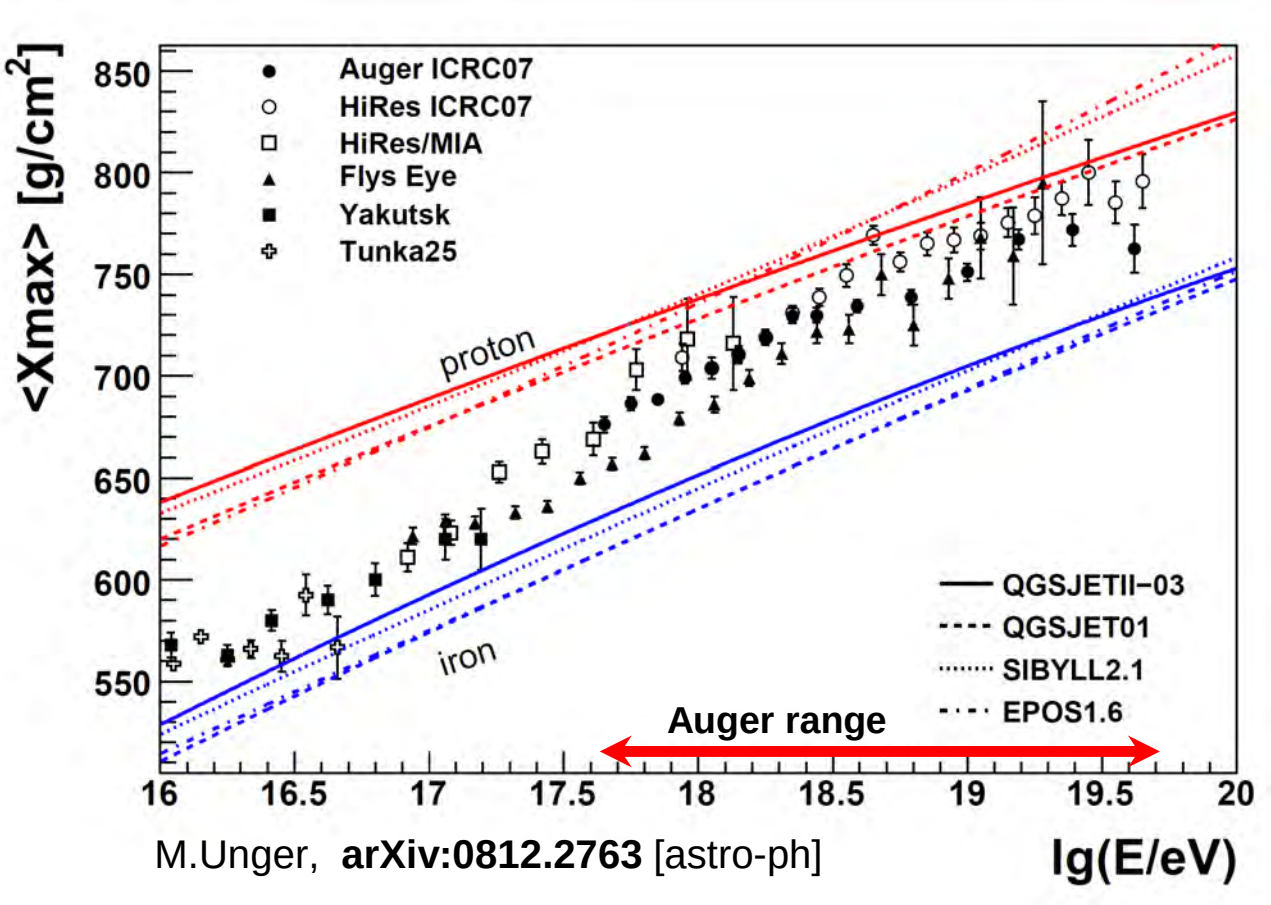
FD Calibration

Optical Spot, Cher. lat. distrib

Results

- Energy spectrum
- **Mass composition**
- Astrophysics
- Search for photons and neutrinos

Mass Composition from X_{max} measurements



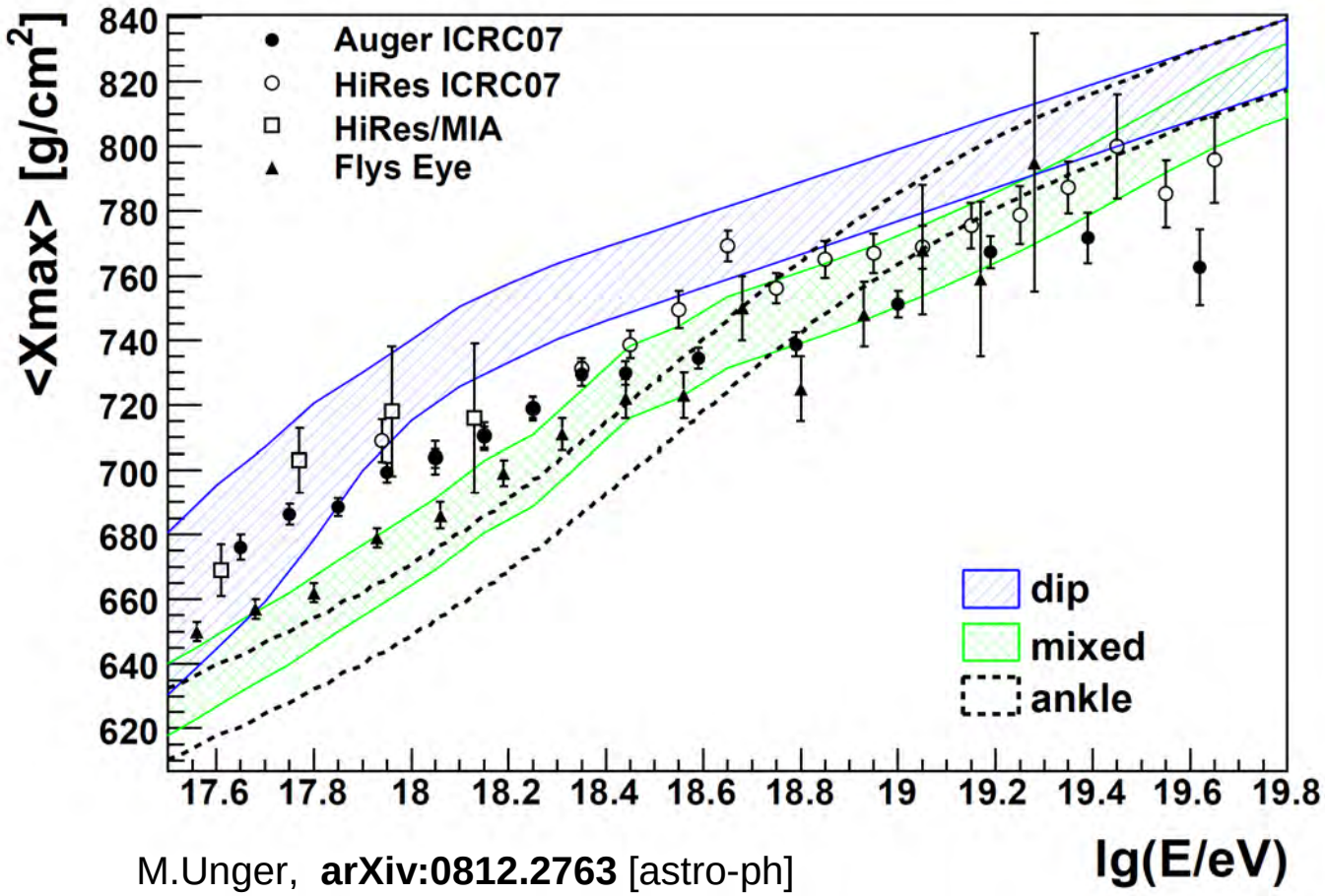
M.Unger, **arXiv:0812.2763** [astro-ph]

P. Auger Observatory data suggest mixed composition at all energies

→ interpretation depends on hadronic interaction models

→ measurements are compatible within experimental uncertainties

Data compared to models



M.Unger, **arXiv:0812.2763** [astro-ph]

none of the model satisfactory explains data yet (shape, absolute value)

→ constraints by studying X_{max} distribution (known syst. unc.)

Results

- Energy spectrum
- Mass composition
- **Astrophysics**
- Search for photons and neutrinos

Anisotropy at the highest energy

Data Set

01/01/2004 – 31/08/2007

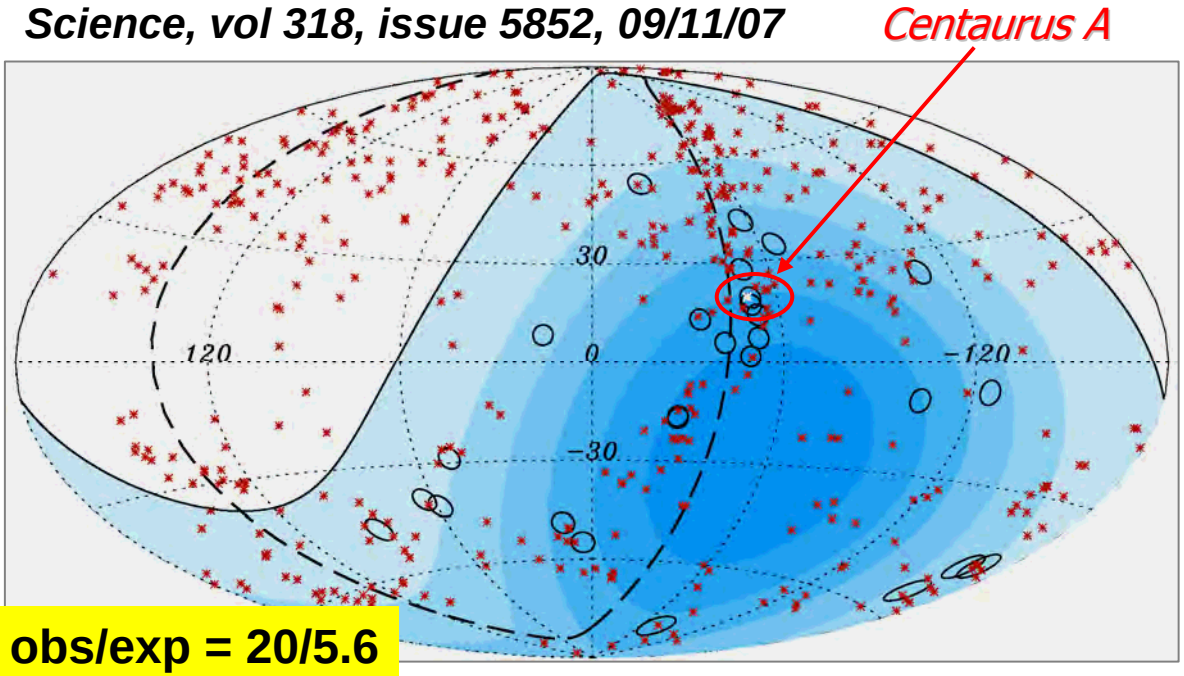
27 high energy events

E>57 EeV
Angular radius of 3.1°
Dmax=75 Mpc

Taking as reference the catalog by Véron-Cetty and Véron (2006)

20/27 events correlate with nearby AGN

Science, vol 318, issue 5852, 09/11/07



obs/exp = 20/5.6

○ *events with E>57 EeV, angular radius ψ = 3.1°,*

× *472 AGN within D_{max}=75Mpc (318 in the Auger FOV)*

Isotropic chance probability < 1%

Limitations of the catalogue: incomplete and inhomogeneous

f.a.q. since November 2007

What do data say up to now?

f.g.a: *Data show a correlation with the local distribution of matter within a few hundred of Mpc and are inconsistent with the expectation from an isotropic distribution*

A quantitative statement at ICRC09

Open Issue:

Anisotropy consistent with a proton based composition

Xmax measurement suggest mixed composition

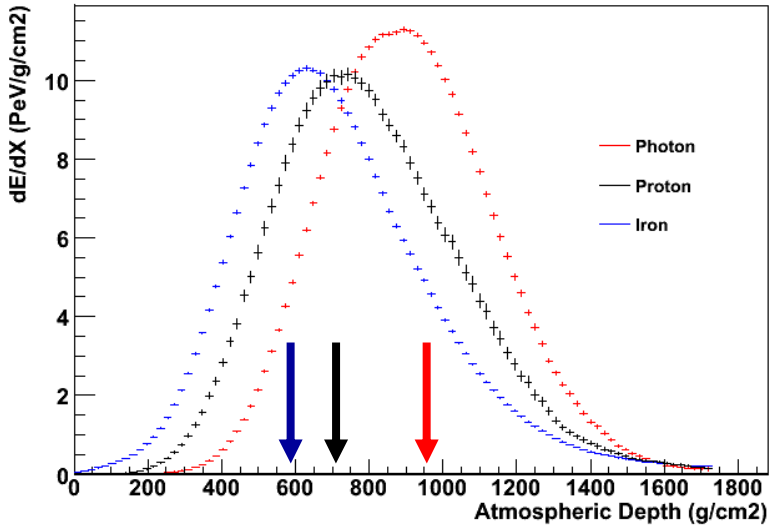
Anisotropy not confirmed by HiRes (northern Hemisphere)

Astroparticle Phys. 30 (2008) 175

Results

- Energy spectrum
- Mass composition
- Astrophysics
- **Search for photons and neutrinos**

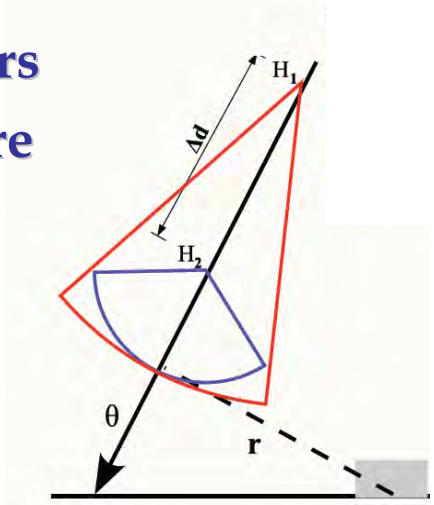
Search for photon primaries



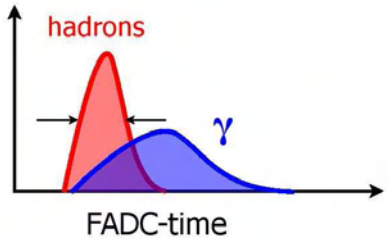
Photon showers develop deeper in the atmosphere

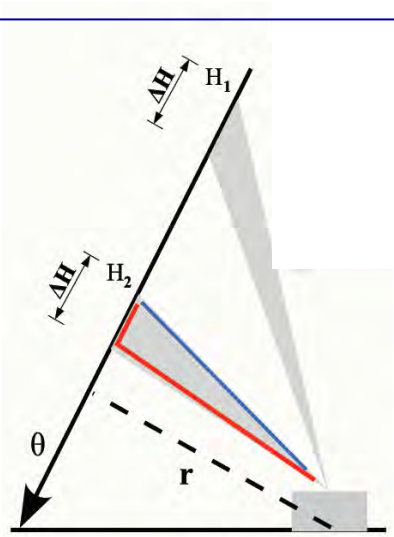
FD: search for events with deep Xmax

Deeper showers larger curvature

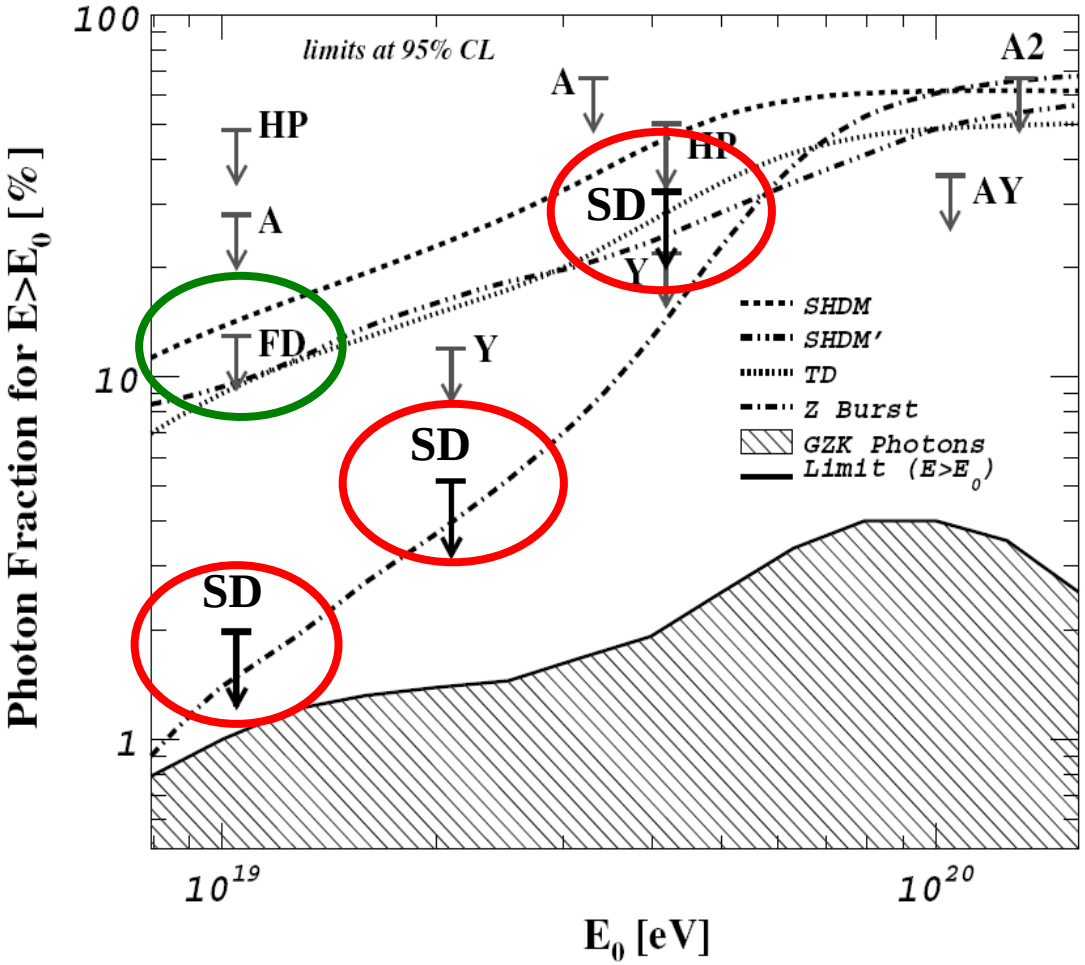


Slower signal, longer risetime





Upper limit on photon fraction



for reference to models & exp. data see

→ M. Risse, P. Homola, Mod. Phys. Lett. A **22** (2007) 749

E>10^{19} eV:

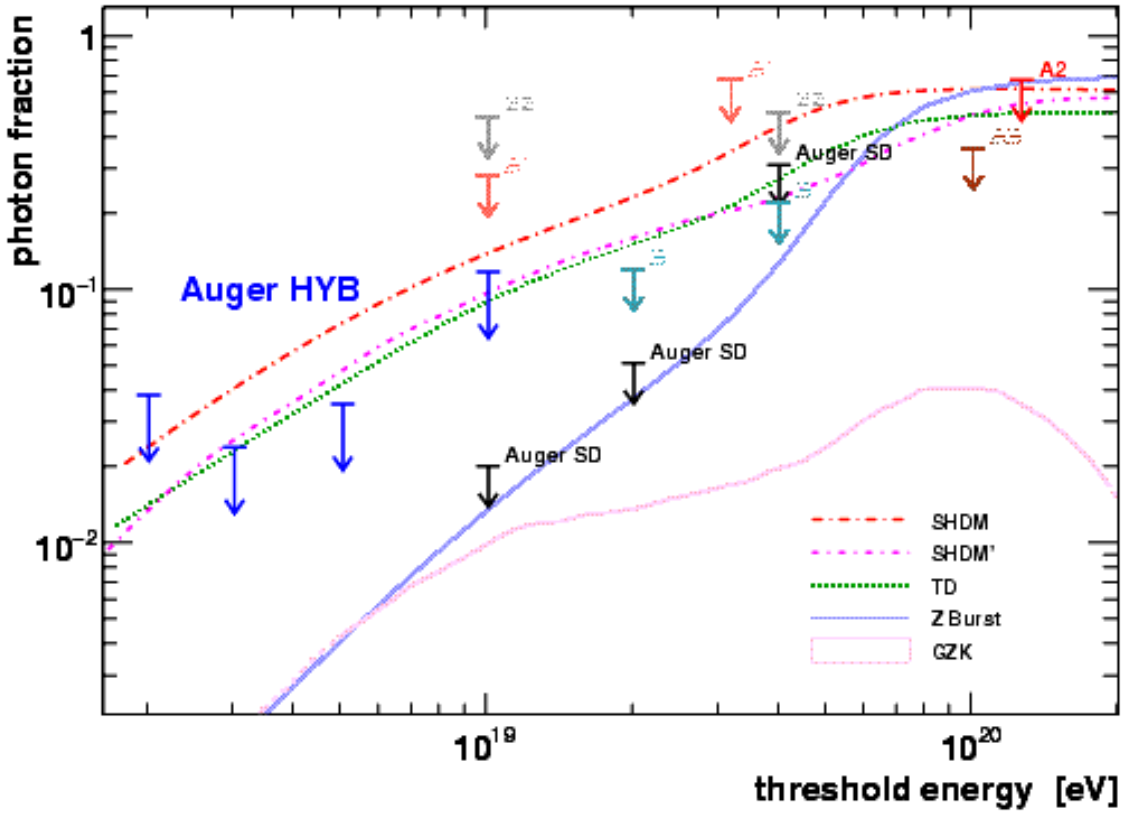
SD: Astrop. Phys. 29 (2008), 243
Based on SD signal rise time and shower curvature

FD: Astrop. Phys 27 (2007), 155
Based on Xmax

top-down models severely constrained!

- favor astrophysical origin of UHECR
- reduce systematics in measurements of energy spectrum, p-air cross section, mass composition

First limits on photon fraction in EeV range



systematics:

X_{max}, Energy

cloud rejection

relative efficiency

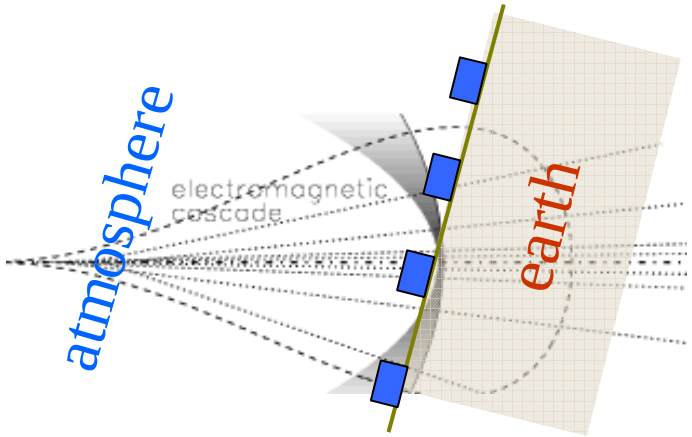
simulations

E (EeV)	F^{ul} (95% c.l.)
2	3.8
3	2.4
5	3.5
10	11.7

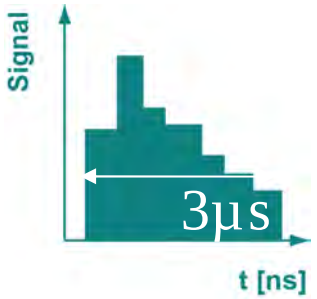
V. Scherini **44th Rencontres de Moriond,** Feb 2009

arxiv.org/pdf/0903.1127v1

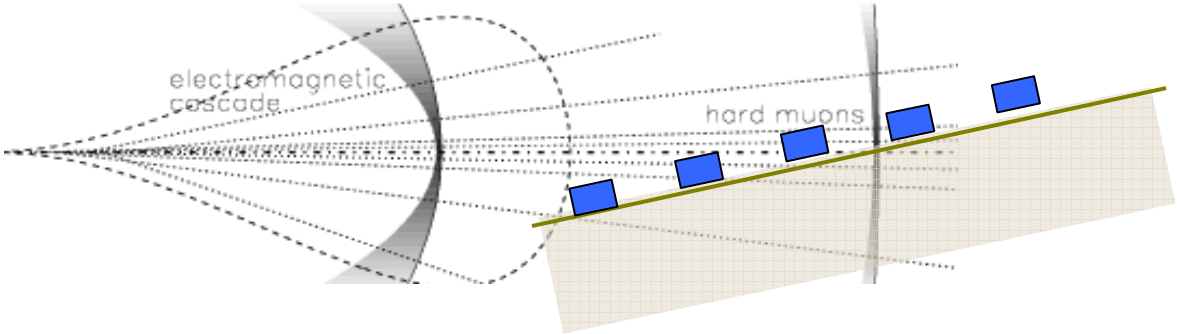
Search for neutrinos

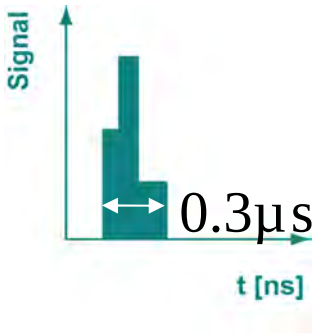


Almost vertical
muons + electromagnetic



Very inclined, thin flat front
high energy muons

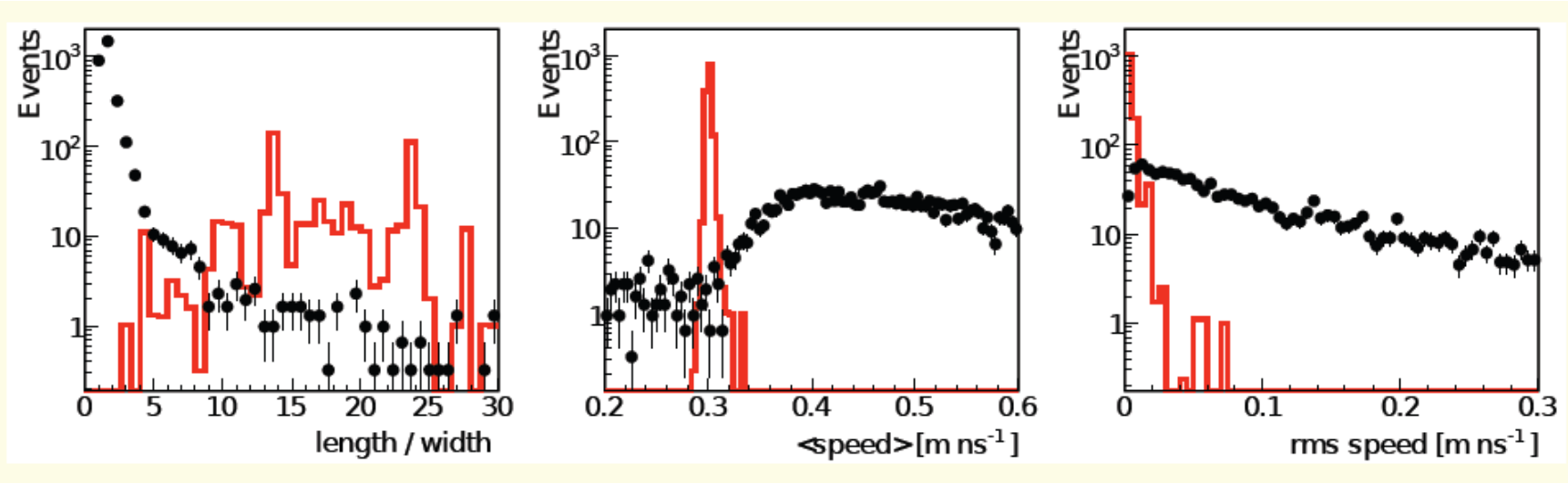




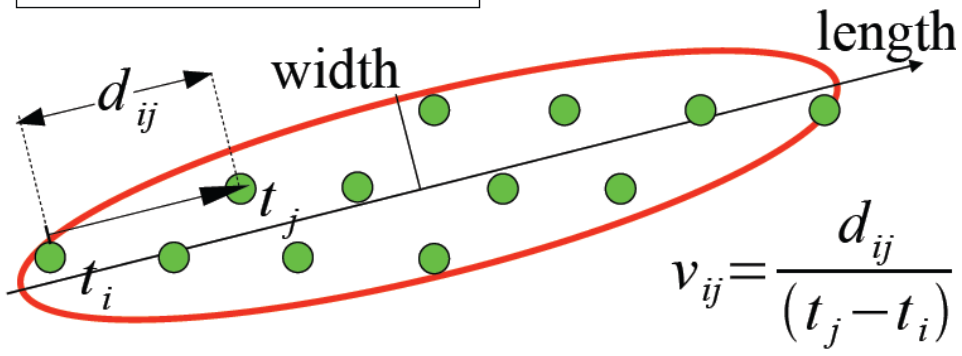
Important for neutrino detection: observable only if almost horizontal

Neutrino signature: an inclined shower with large electromagnetic component

Neutrino-like event selection



Inclined Showers



Data

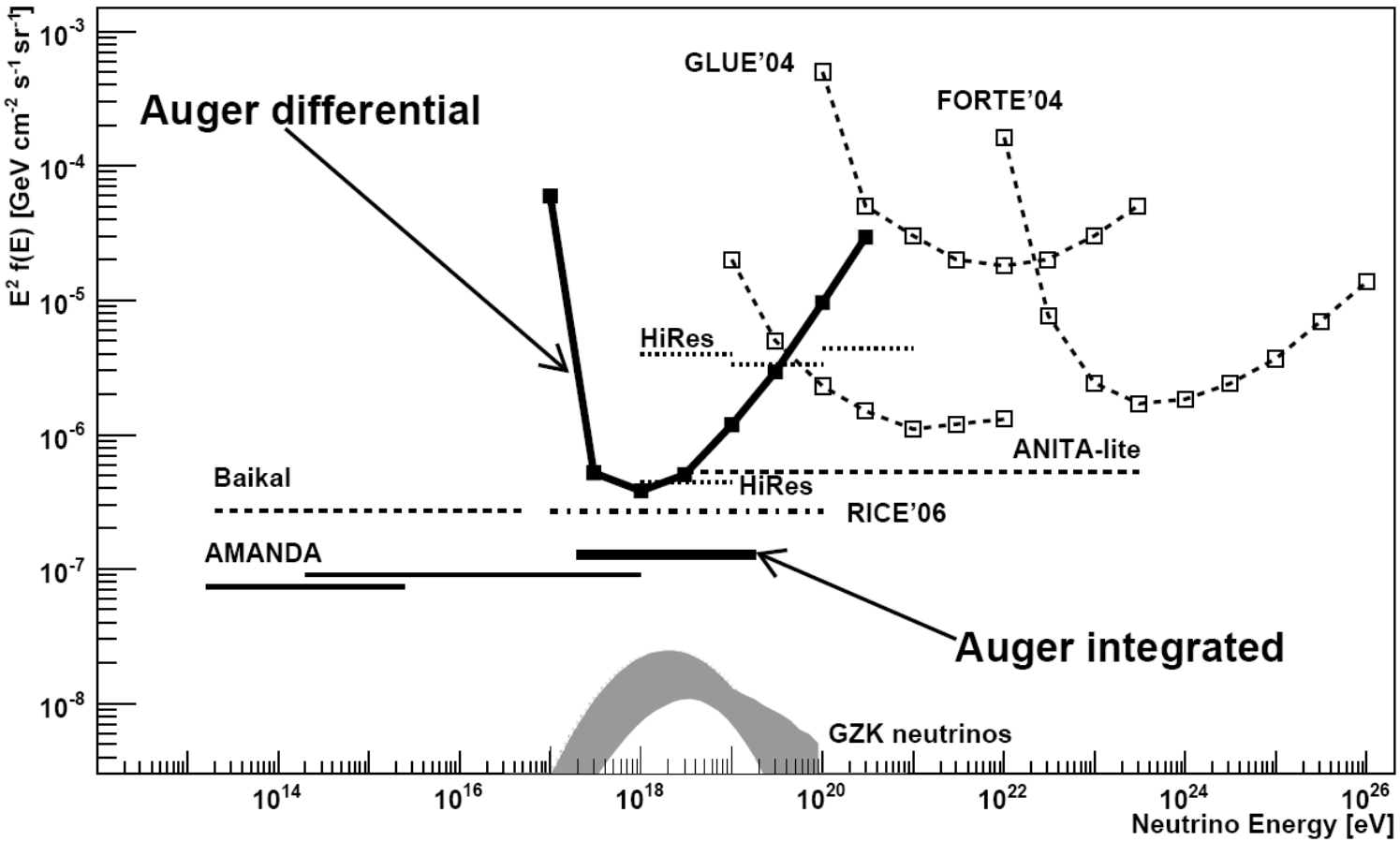
Simulated neutrino signal

Length/width >5

0.29< speed < 0.32 m/ns

rms< 0.08 m/ns

Upper limit on diffuse neutrino flux



Phys. Rev. Lett.,100 (2008)

Future plans for Auger

Physics Case I

- improve detector performance at the transition to extragalactic component (~10^{17} – 10^{18} eV)
- cross calibration with other experiments (Kascade Grande)

Auger FD and SD Enhancements under construction

Physics Case II

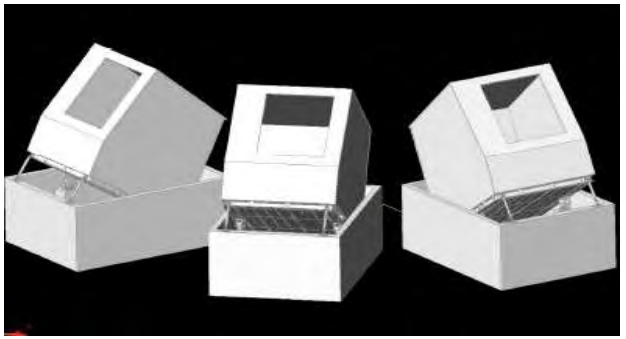
- Full coverage sky
- Higher energies, greater acceptance

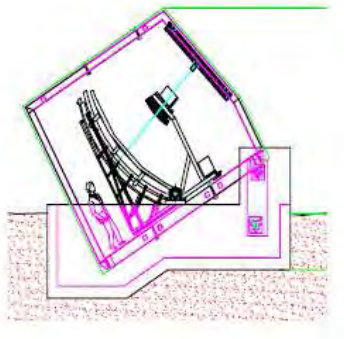
Auger North: proposal, R&D stage

FD Auger enhancements

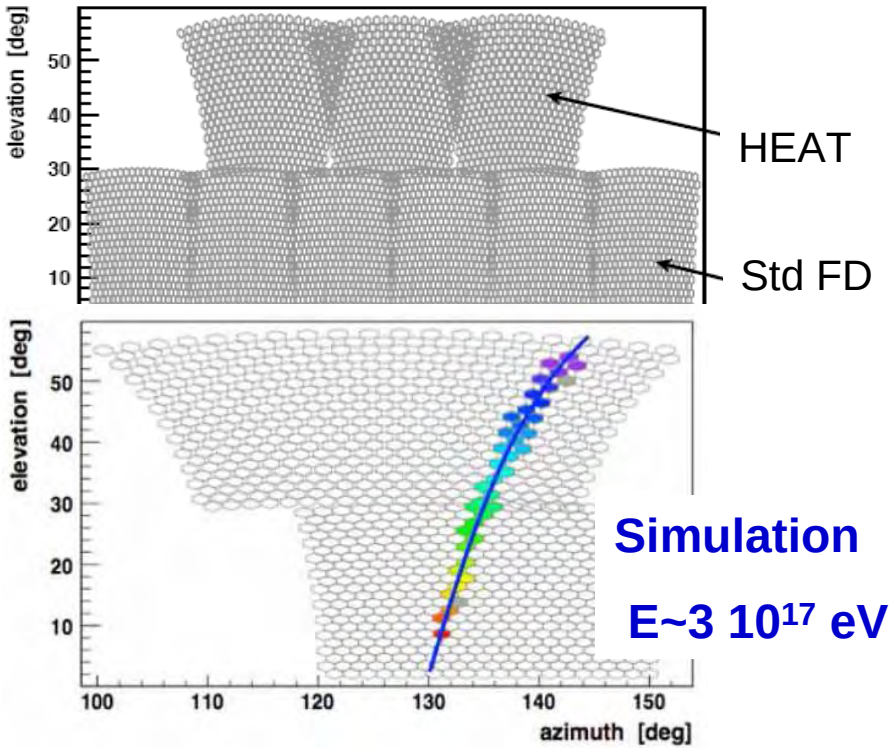
HEAT

- 3 telescopes nearby Coihueco
- 30° up to 60° elevation





First light on 30/01/2009!



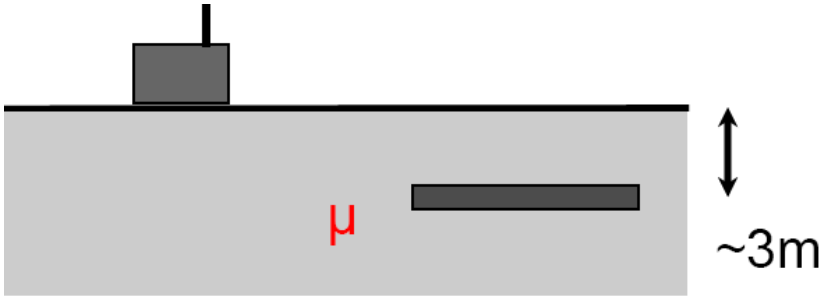
Simulation

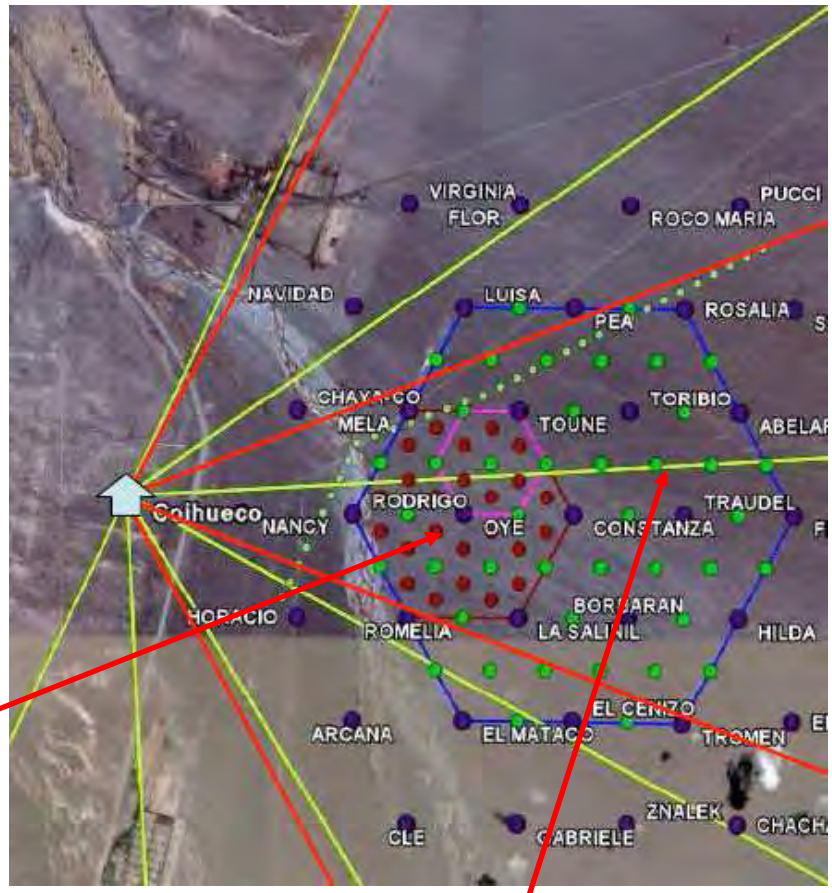
E~3 10^{17} eV

SD Auger enhancements

AMIGA

- infill array
- muon detectors (scintillators)



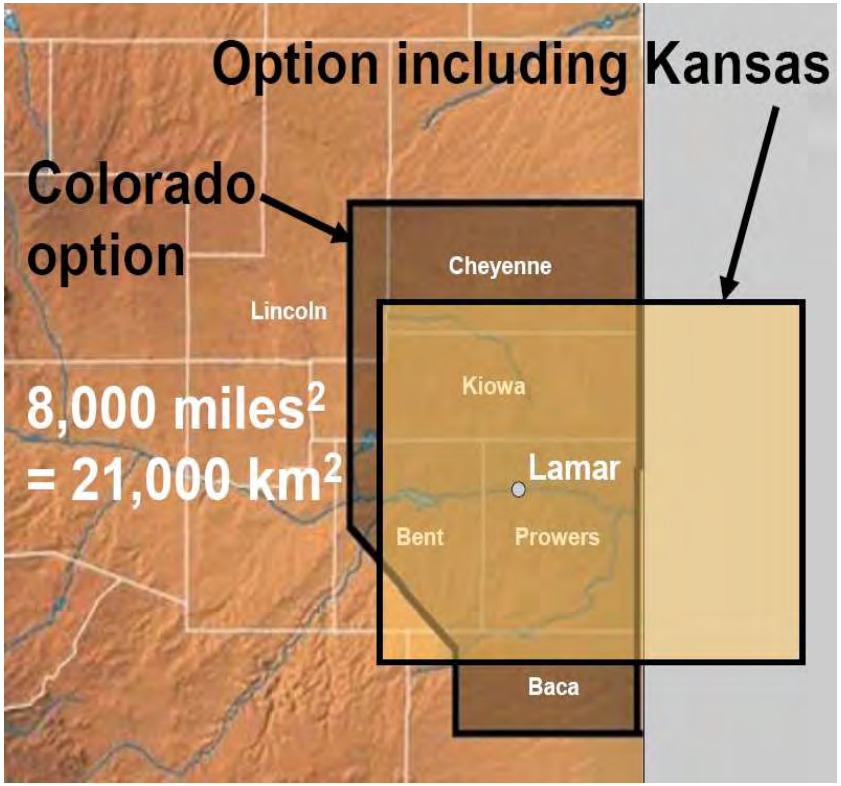


5.9 km² (24 detectors)
Infill Array 433m

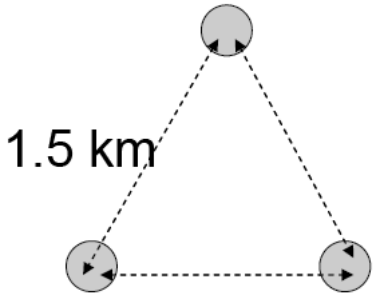
23 km² (42 detectors)
Infill Array 750m

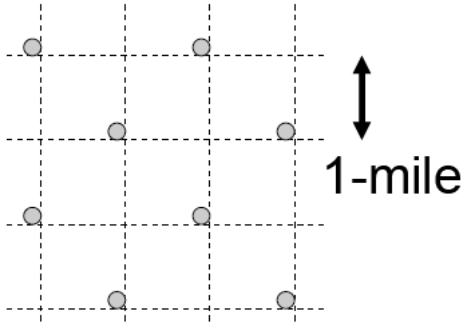
Auger north

Site: Colorado, Lamar



South	North
SD units 1,600	4,400
SD area 3,000 km²	20,000 km²
3 PMT's	1 PMT
Non-insulated	Insulated
tank→center comms	tank→tank





Conclusions

The Pierre Auger Observatory (south site) takes data smoothly since 2004

First results extremely encouraging

- Energy spectrum

  Flux suppression at E>4 10^{19} eV observed (conf. by HiRes)

  hints on imminent updated results for hybrid spectrum

- Composition

- Arrival directions

- Search for neutrino and photons

  new limits to photon fraction in EeV range

New results with higher statistics are imminent (ICRC09)

Enhancements (HEAT, AMIGA) will allow covering lower energies

The northern site will provide full sky coverage and larger acceptance

Comparison with other incoming projects (TA) will help clarifying open issues