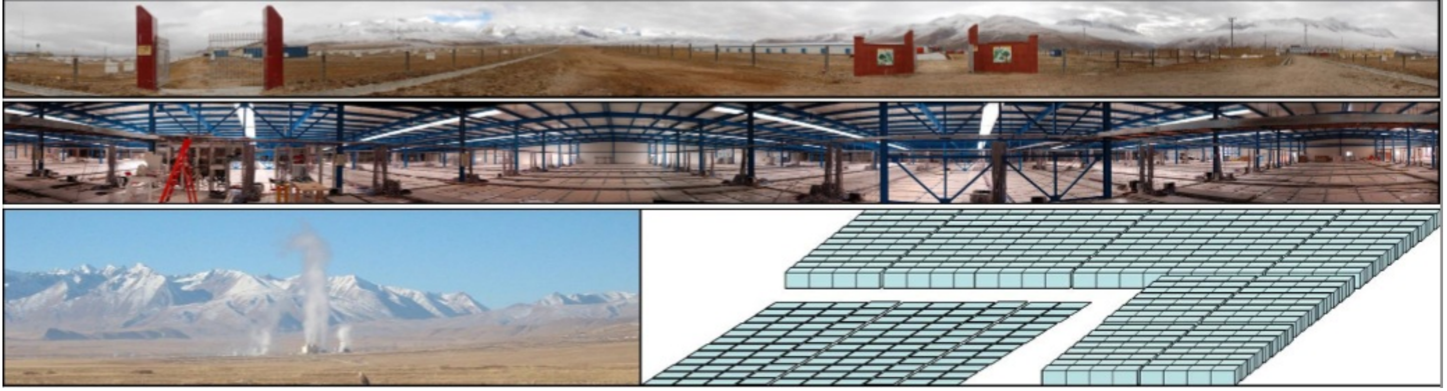
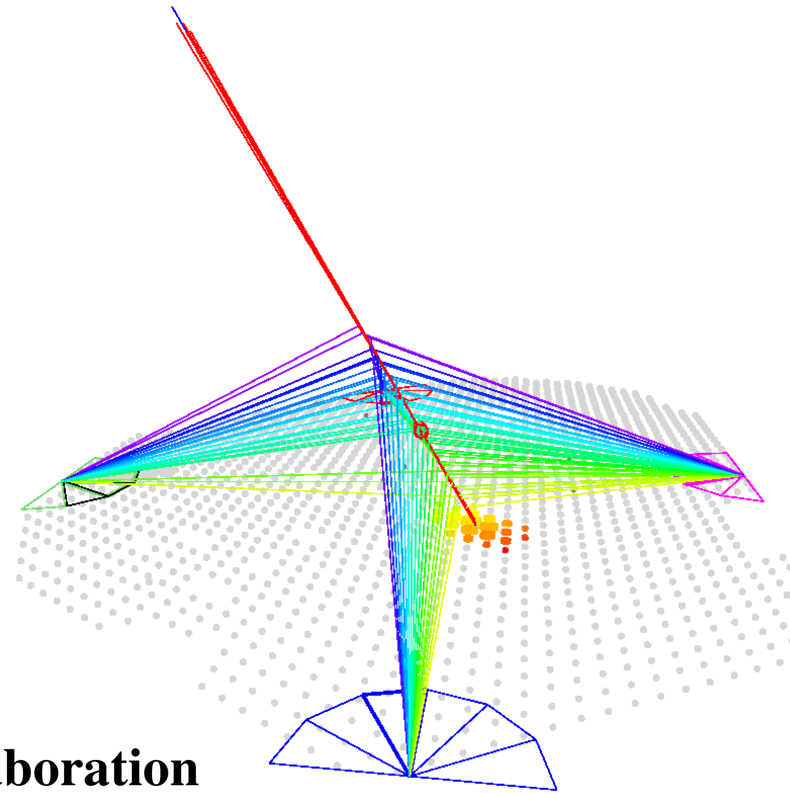


PIERRE AUGER OBSERVATORY

4th Workshop on Air Shower Detection at High Altitude

Results from the Pierre Auger Observatory



Lorenzo Perrone for the Pierre Auger Collaboration

Università del Salento and INFN Lecce (Italy)

The physics case

Study of the transition between galactic and extra-galactic cosmic rays

- Ankle region

- 2nd Knee region (with lower energies extensions ENHC)

End of the spectrum (GZK region)

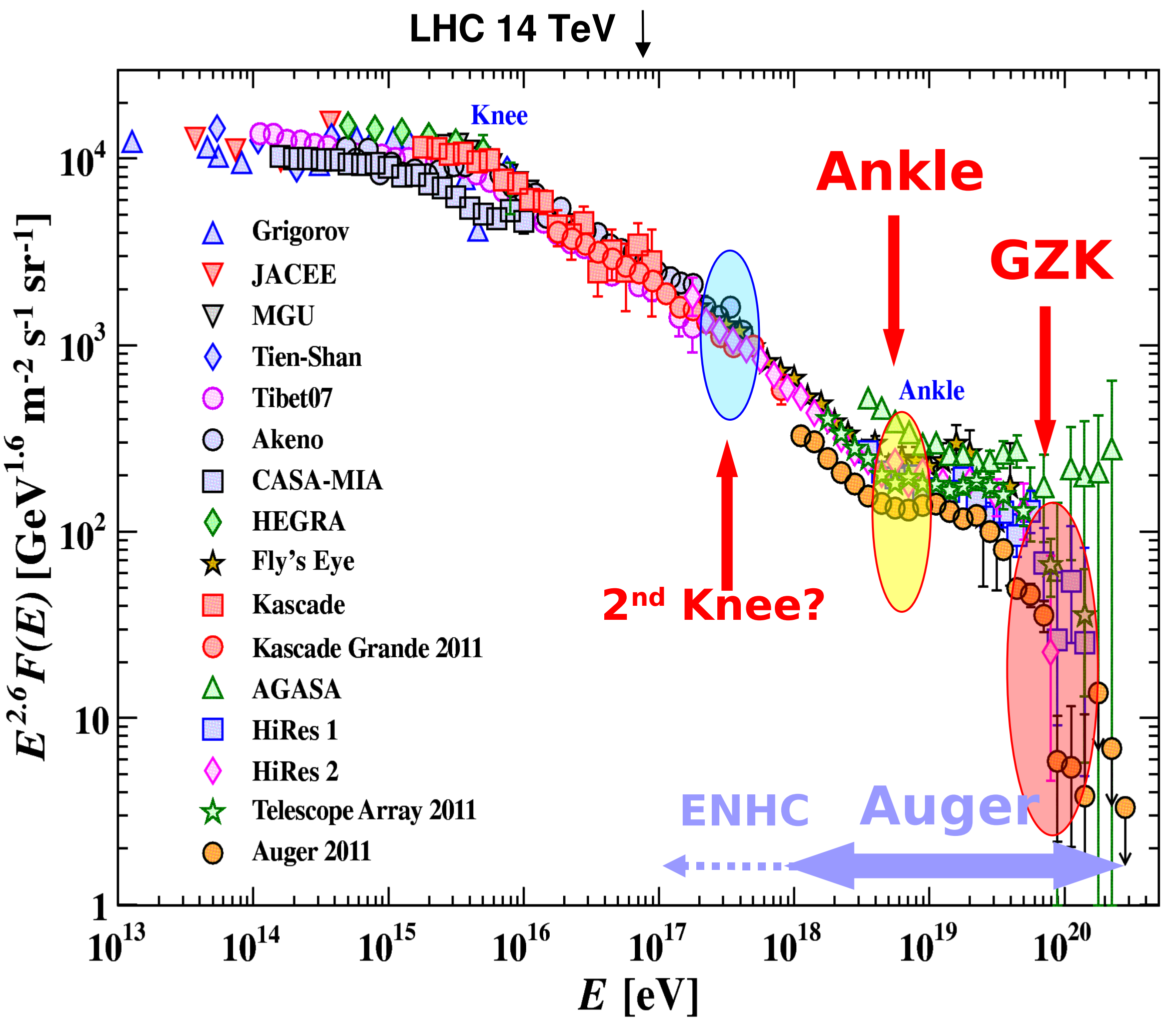
Energy spectrum

Arrival directions

Composition

Search for photon and neutrinos as primary cosmic rays

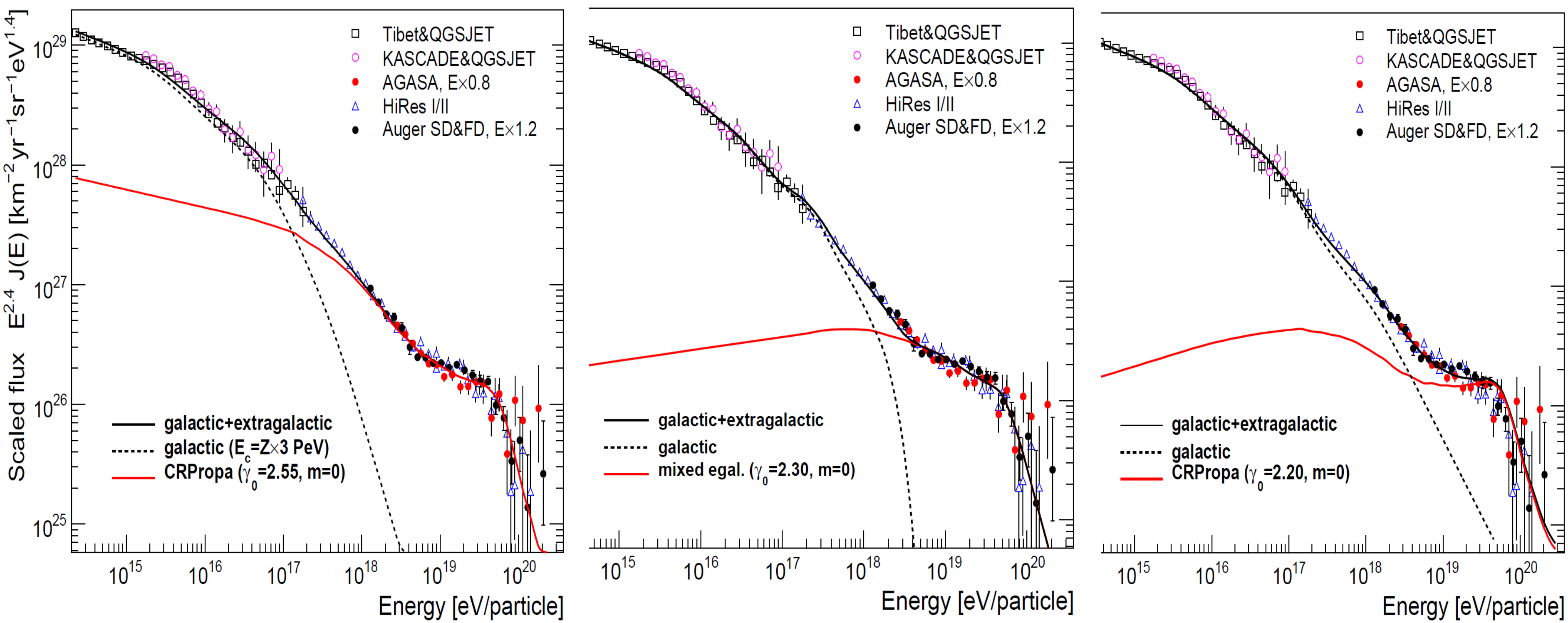
Hadronic physics



Particle Data Group

“the ankle”: models and hypotheses

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



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

Dip Model
Extragal. protons
(Berezinsky et al.)

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

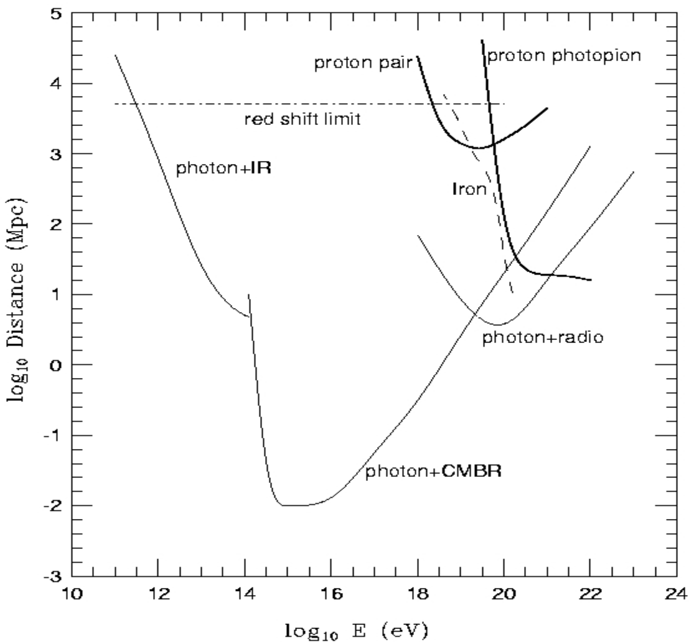
Mixed comp. of
extragal. component
(Allard et al.)

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

Extragal. protons
(ankle model)

End to the cosmic ray spectrum?

Greisen Zatsepin Kuz'min effect (1966):
Interaction with the cosmic microwave background (CMB)



propagation scenario

protons:

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

$$\left.\begin{array}{l} p + \gamma_{CMB} \rightarrow \Delta^+ \rightarrow p + \pi^0 \\ p + \gamma_{CMB} \rightarrow \Delta^+ \rightarrow n + \pi^+ \end{array}\right] \; E \geq 7\ 10^{19}\ \text{eV}$$

nuclei: photo-disintegration and pair production on CMB (RB IR)

"horizon" (p and nuclei) ~ 100 Mpc (~10^{20} eV)

source scenario

We may be observing the end of cosmic ray accelerators "fuel". **$E_{max} \propto Z\ B\ R$**

The knowledge of composition at the highest energies and the detection of cosmogenic neutrino and/or photons is the main challenge for near future

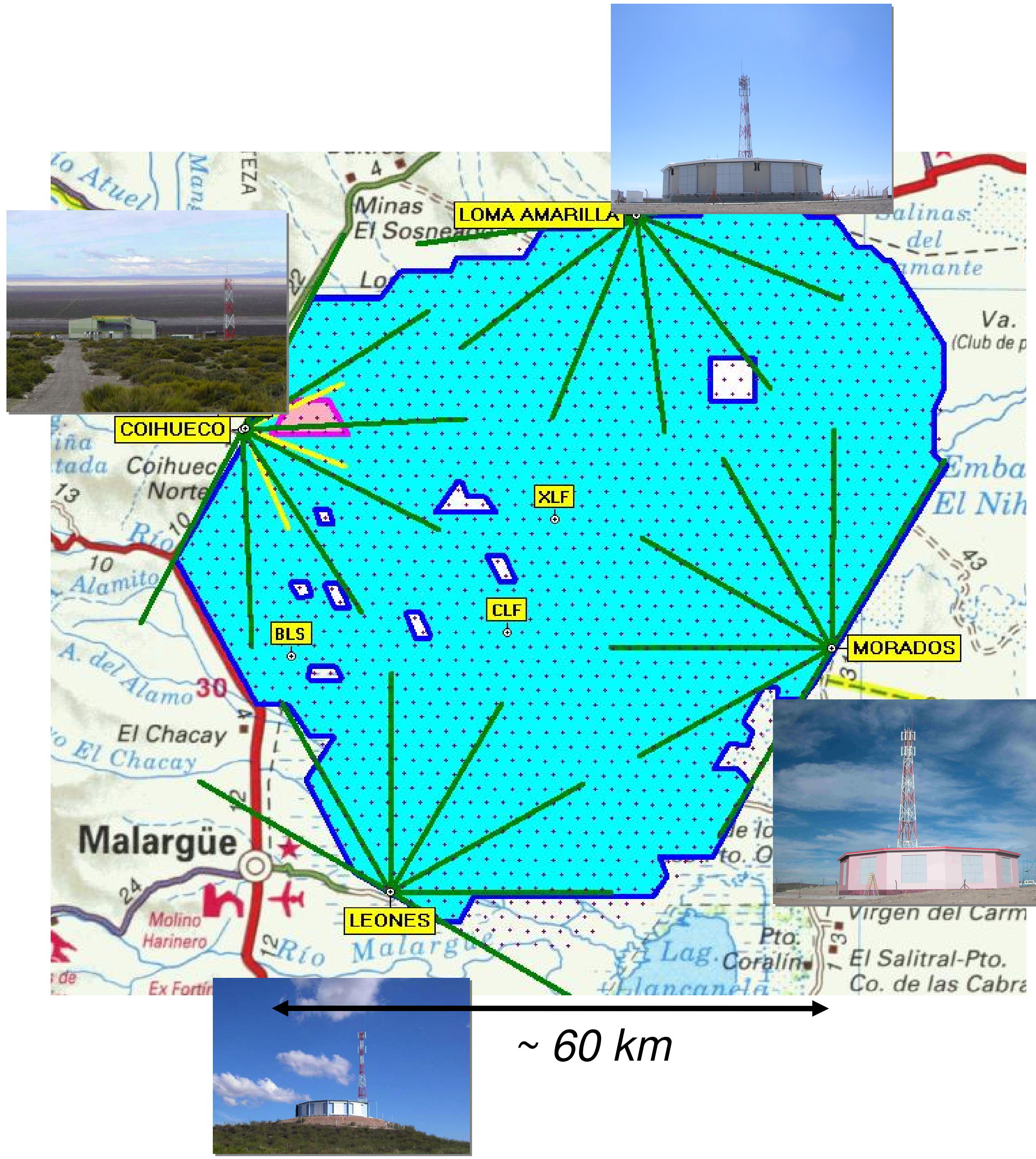
The Pierre Auger Observatory

- ***Surface detector***

an array of 1660 Cherenkov stations on a 1.5 km hexagonal grid (~ 3000 km^2)

- ***Fluorescence detector***

4+1 buildings overlooking the array (24+3 telescopes)



Low energy extensions

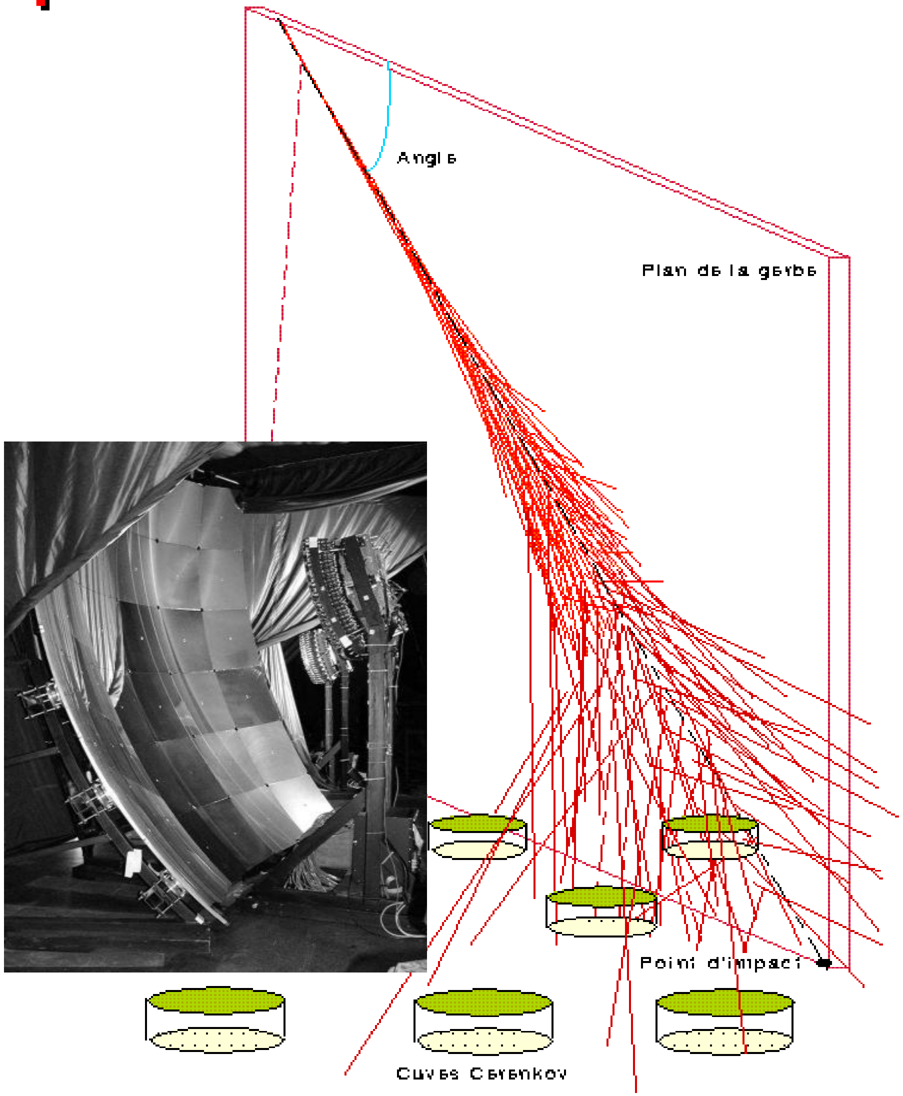
AMIGA: dense array plus muon detectors

HEAT: three further high elevation FD telescopes

The Hybrid Concept

Surface Detector Array
lateral distribution, 100% duty cycle

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



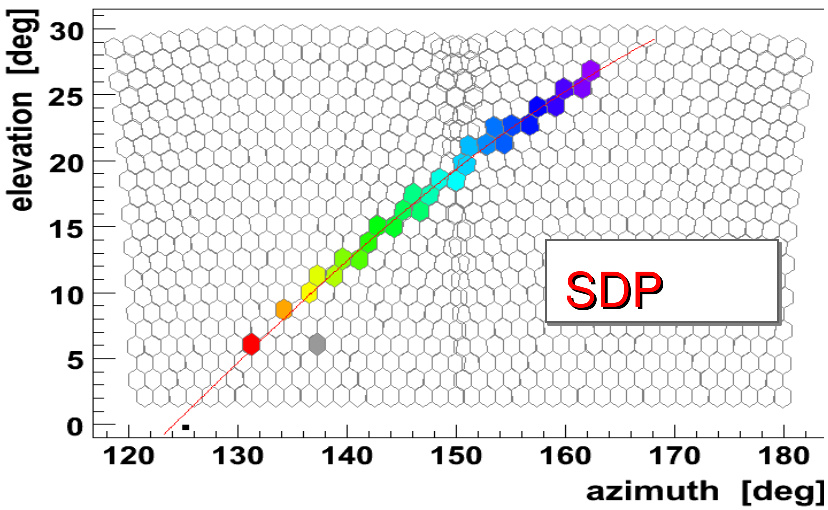
accurate energy and direction measurement

mass composition studies in a complementary way

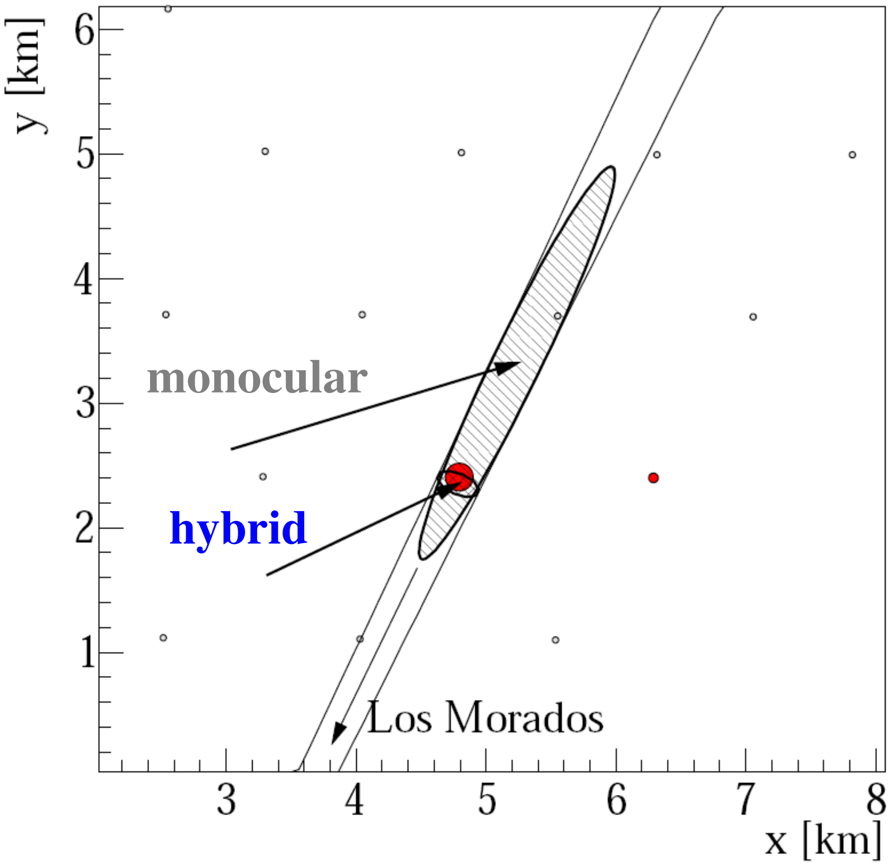
Results

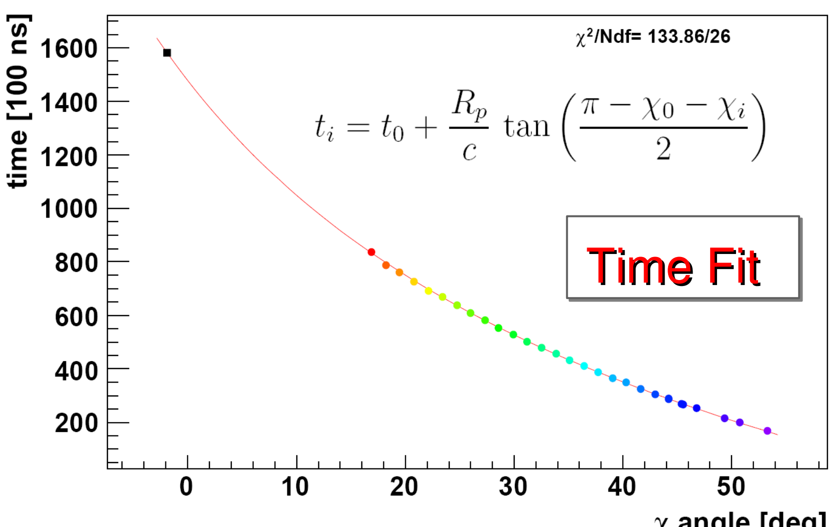
- **Energy spectrum (hybrid, SD, combined)**
- Mass composition
- Hadronic interactions
- Astrophysics
- Search for photons and neutrinos

FD-Hybrid geometry reconstruction



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



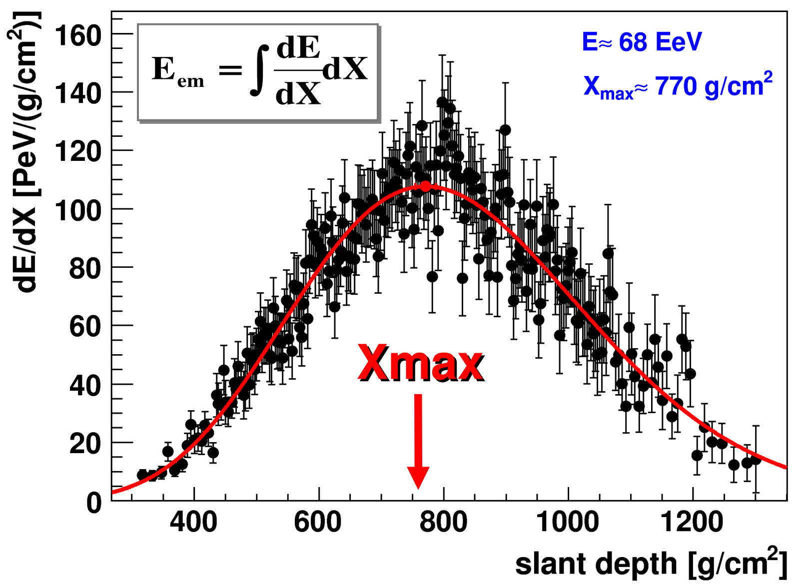


Hybrid angular resolution ~ 0.6°

Core resolution about 50 meters

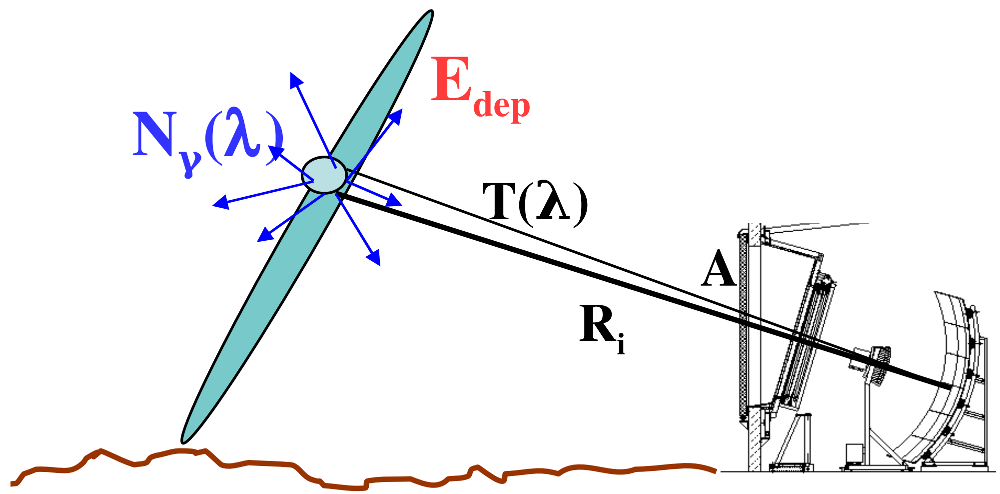
FD: energy determination

Longitudinal Profile



Energy "Calorimetric measurement"

Almost model independent



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

Fluorescence yield (from laboratory measurements)

Geometry

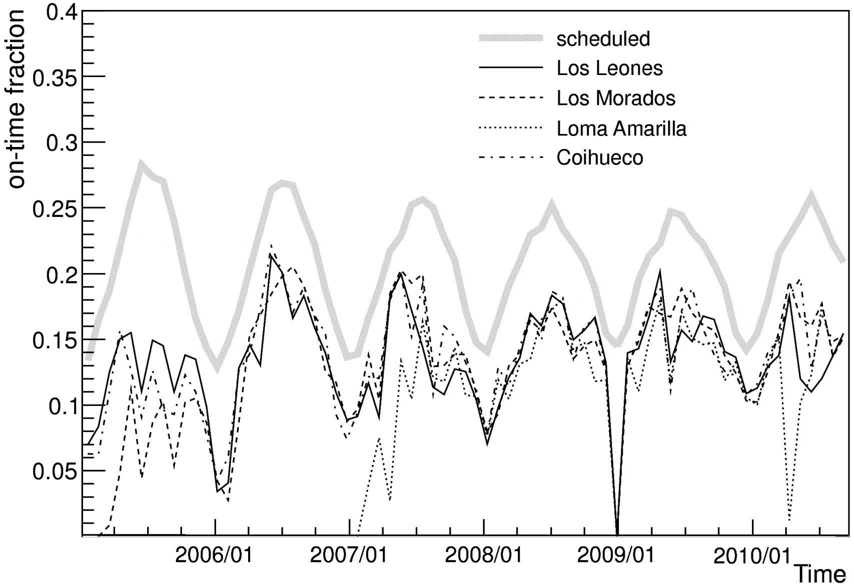
$$\frac{A}{R_i^2}$$

Atmosphere

$$T(\lambda)$$

Detector calibration

Hybrid Performance

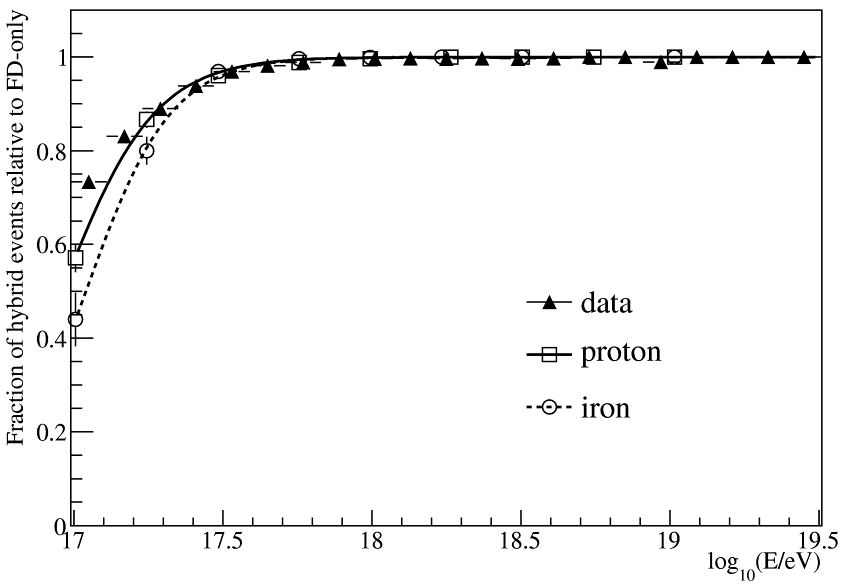


Data: Nov. 2005 – Sept. 2010

average duty cycle (~14%)

FD on-time and SD stations status reproduced in simulation according to the actual data taking conditions, in time slices of 10 minutes.

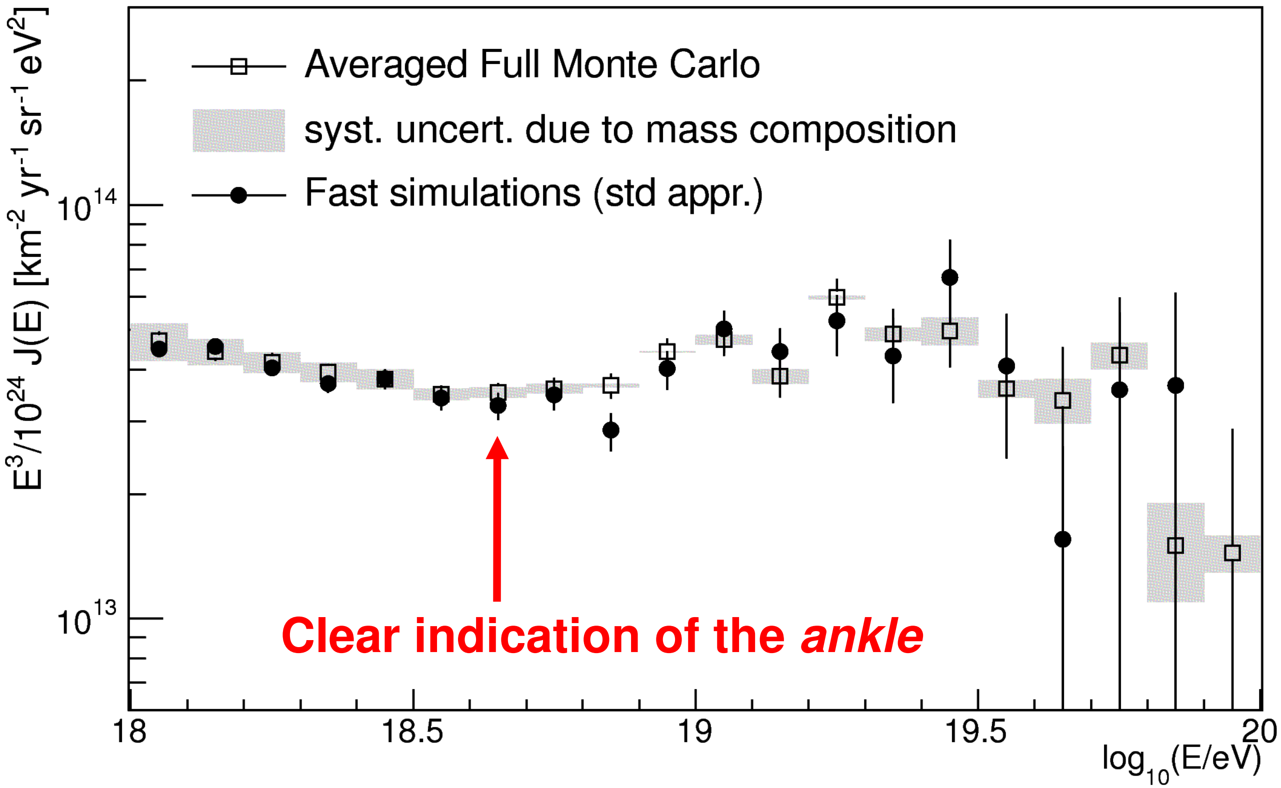
+ Full efficiency at 10^{18} eV (ankle region)
+ Calorimetric measurement
+ Energy Resolution of 8%



Astropart. Phys. 34 (2011) 368

Hybrid Energy Spectrum

M. Settimo for the Pierre Auger Coll., Eur. Phys. J. Plus 127 (2012) 87



Nov. 2005 – Sept. 2010

Two independent methods

Full Monte Carlo: Corsika+Geant4 ("limited" statistics, signal in the stations)

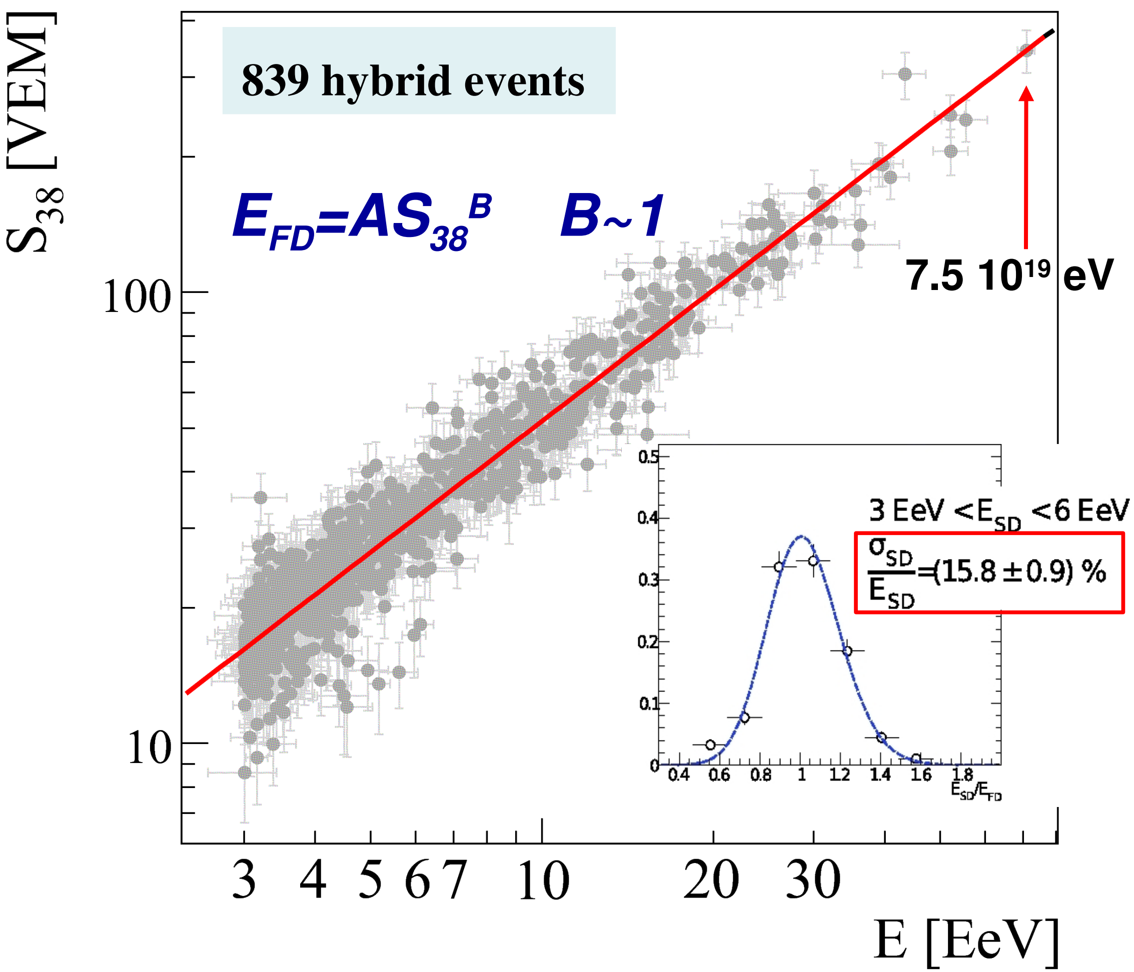
Standard Method: Conex longitudinal profiles with a parametrized SD trigger response (huge statistics, allows stricter analysis cuts)

Different analyses yield very similar results

Nice confirmation for the resulting spectrum

Energy calibration

R.Pesce @ **ICRC 2011**



Jan 2004 – Sept 2010
E > 3 EeV - zenith < 60°

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

Method Systematic Uncertainties
7% a 10^{19} eV
15% a 10^{20} eV

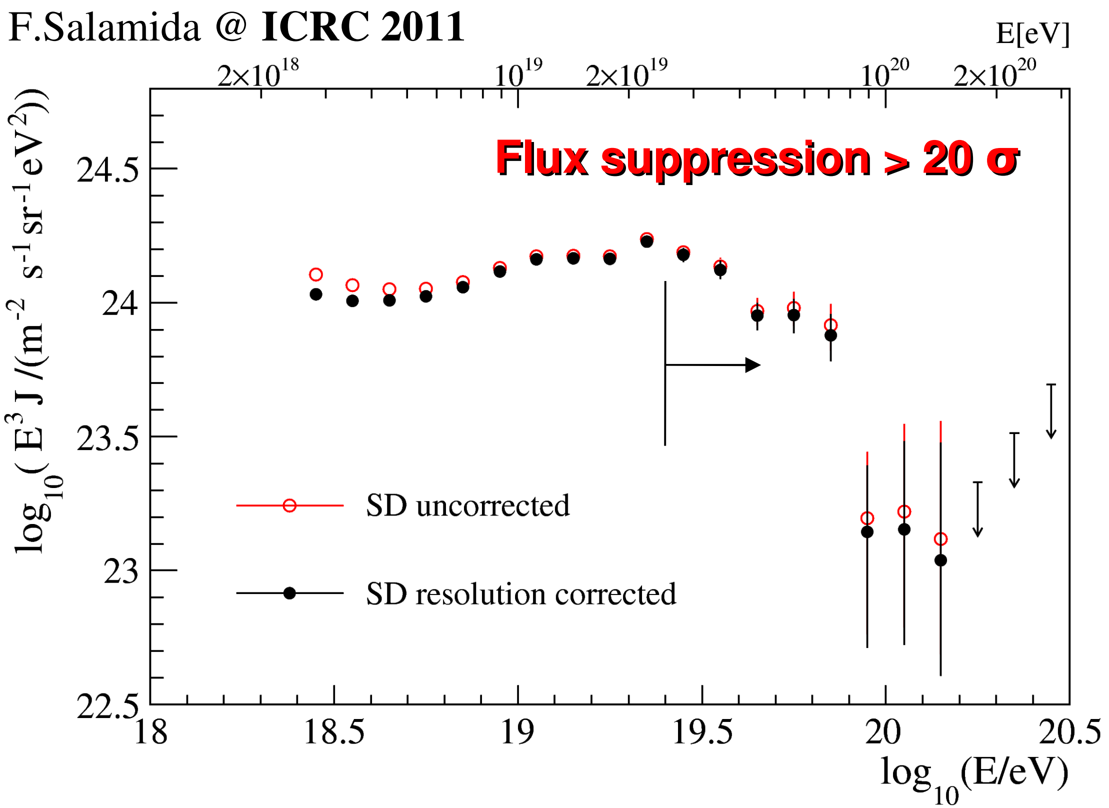
FD Energy Systematics

- fluorescence yield 14%
- FD absolute calibration 9.5%
- invisible energy 4%
- reconstruction 10%
- atmospheric effects 8%

TOTAL: 22%

S_{38} *-> S1000 that a shower would have produced had it arrived with a zenith angle of 38°*

SD Energy Spectrum



64000 (5000) events **E > 3 10^{18} eV** (> 10^{19} eV)

SD Exposure

E> 3 EeV and zenith < 60°

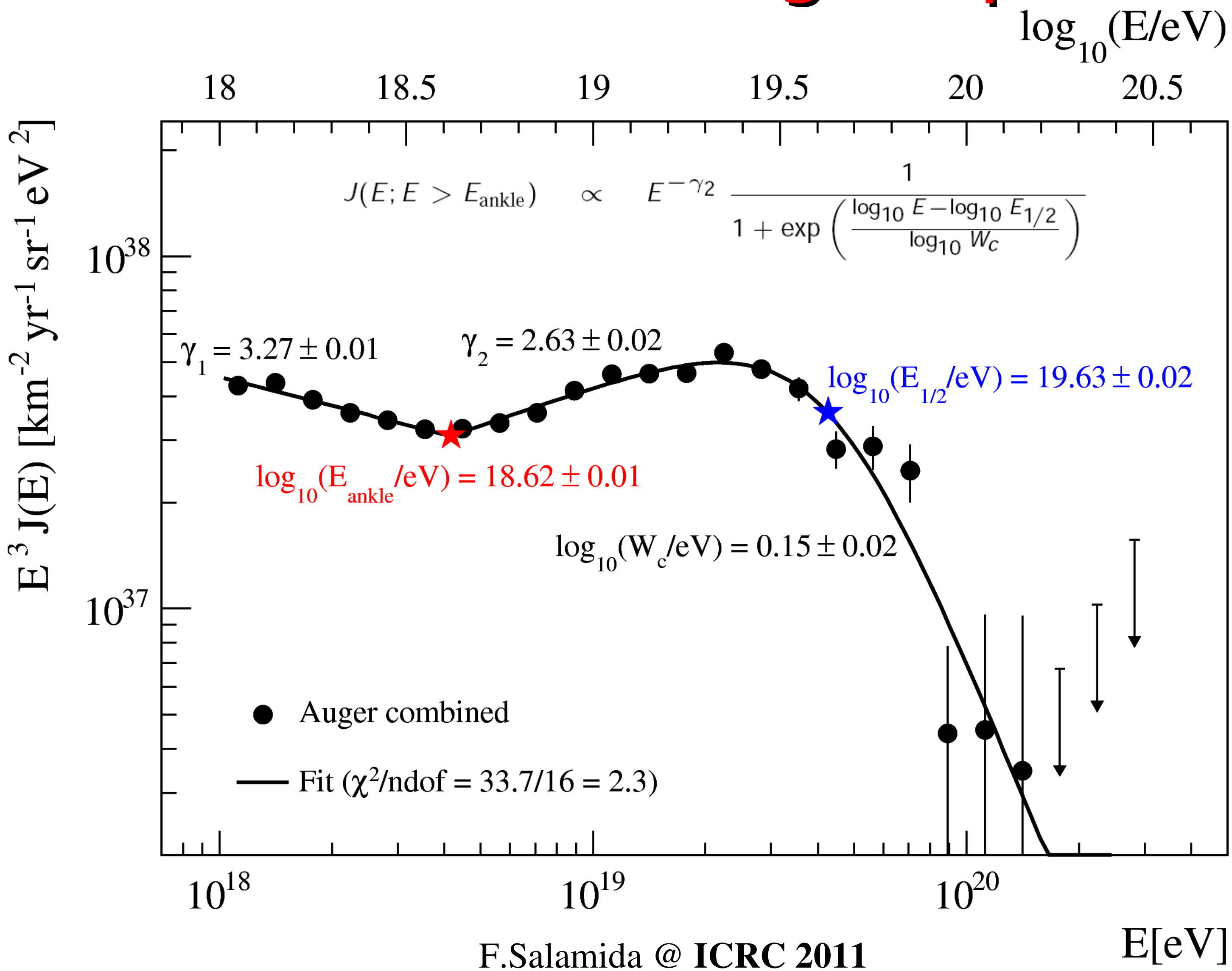
- **20905 km² sr yr (Jan 04 - Dec 10)**
- **geometrical, counting active hexagons. Not relying on simulations, full efficiency**
- **independent of primary mass**
- **3% systematic uncertainty**

Energy scale from FD

Energy resolution ~ 15%
forward folding method to correct
for the bin-to-bin migration

Total systematic uncertainty on flux ~ **6%**
22% on the energy scale

The combined Auger spectrum



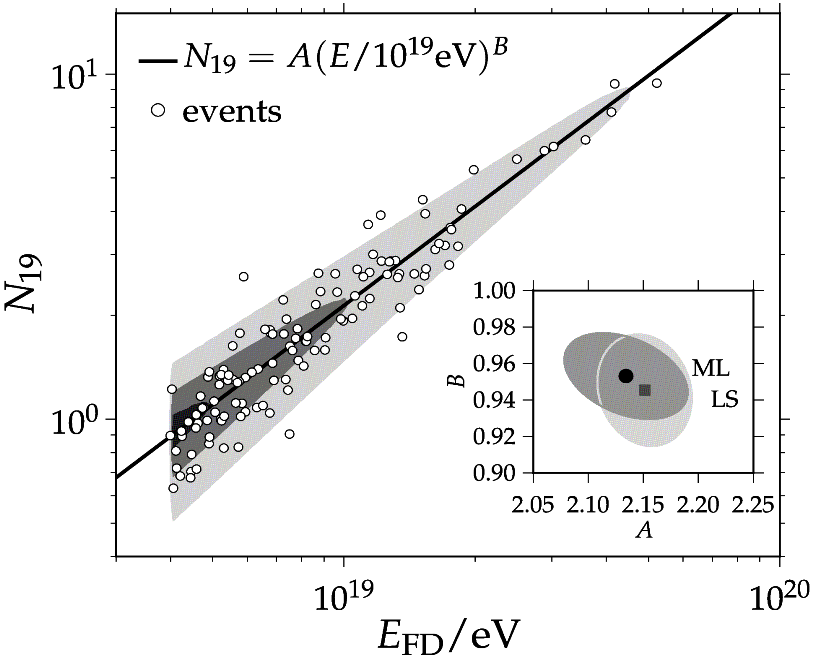
F.Salamida @ **ICRC 2011**

M. Settimo for the Pierre Auger Coll., Eur. Phys. J. Plus 127 (2012) 87

Spectrum with inclined events

H.Dembinski @ **ICRC 2011**

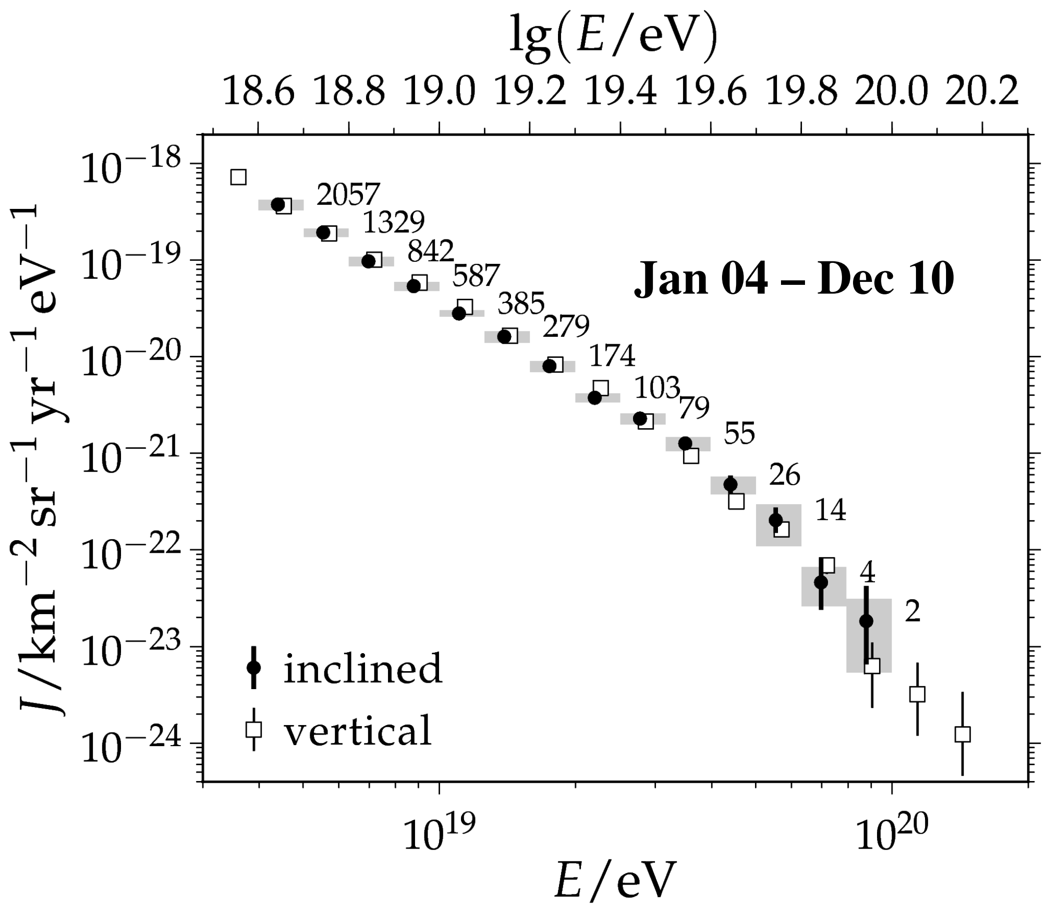
Energy Calibration with FD energy



Energy estimator:
N_{19} -> lateral muon density

- Energy > 4 10^{18} eV

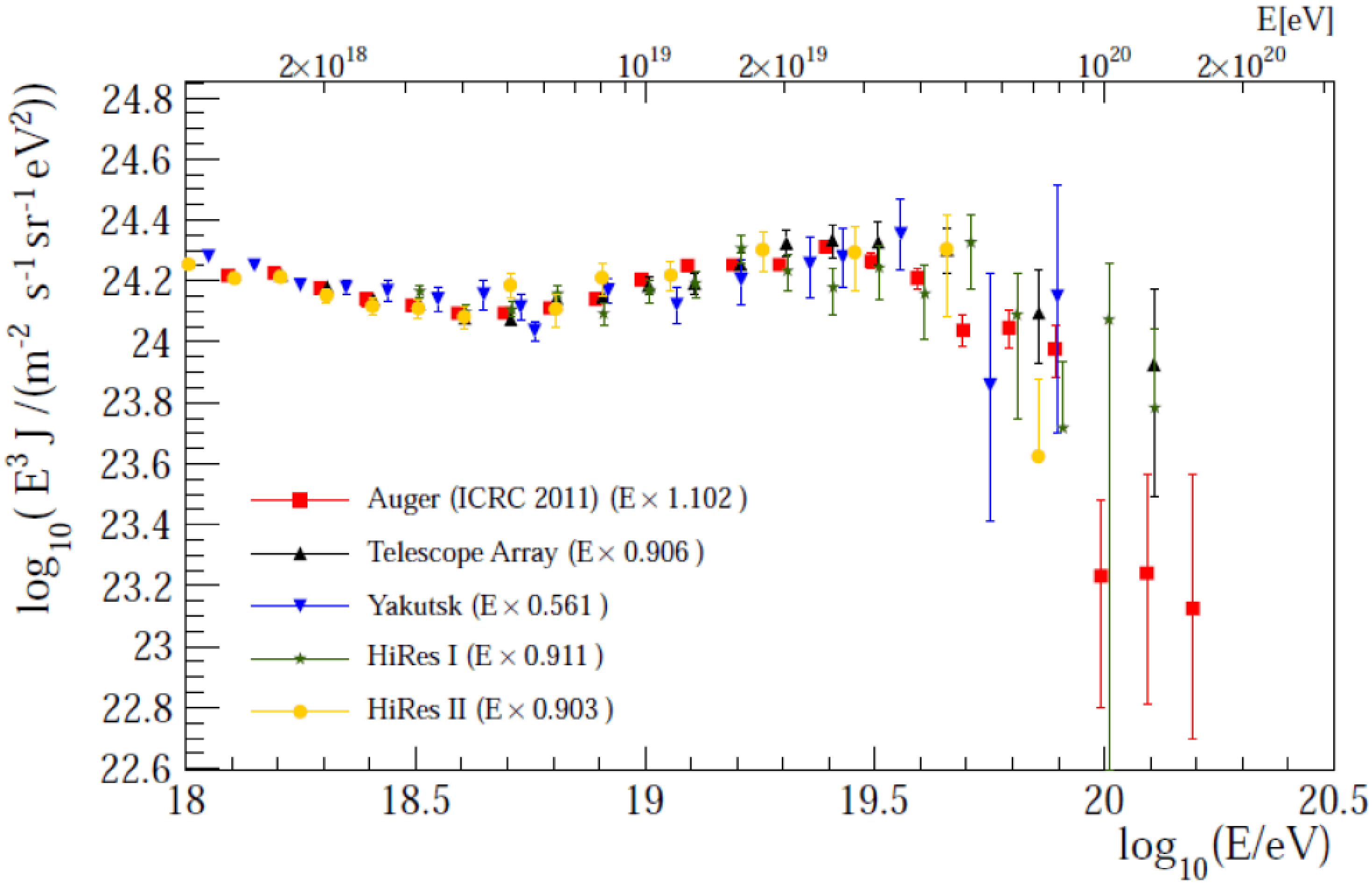
- 62° < Zenith< 80°



Full agreement with flux from vertical showers

Energy spectrum comparison

Y. Tsunesada et al. @ **UHECR 2012**

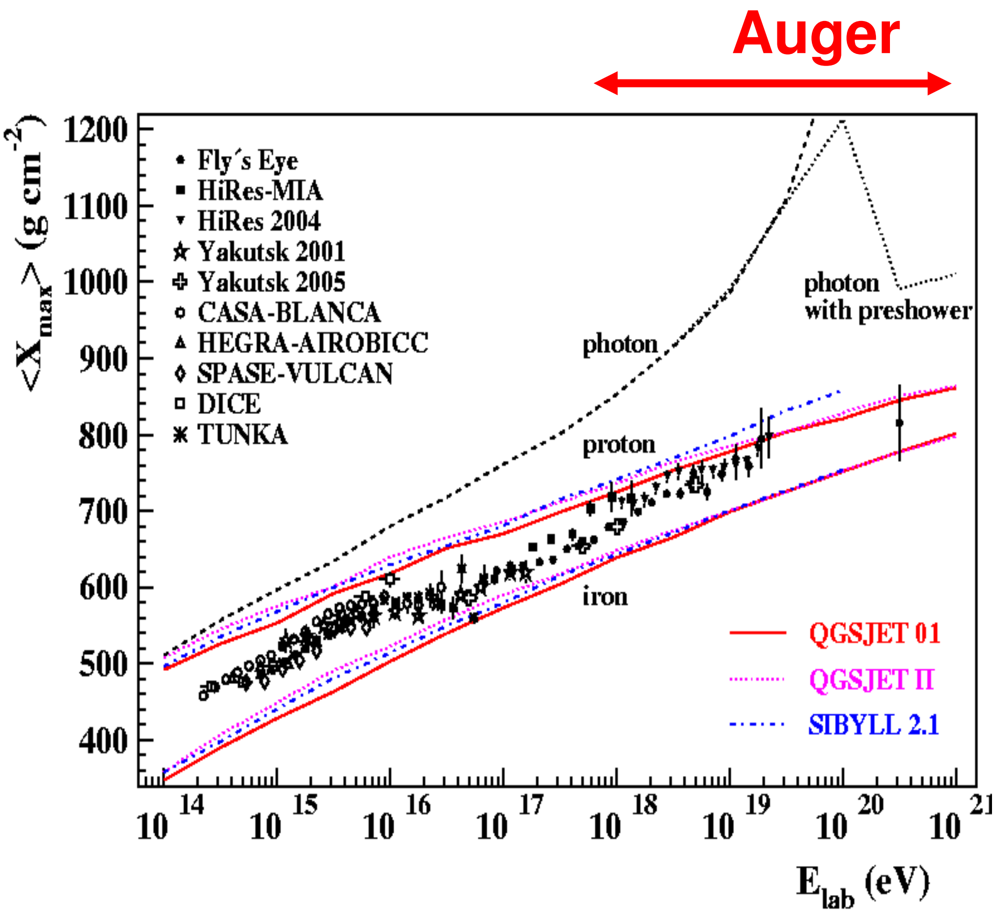


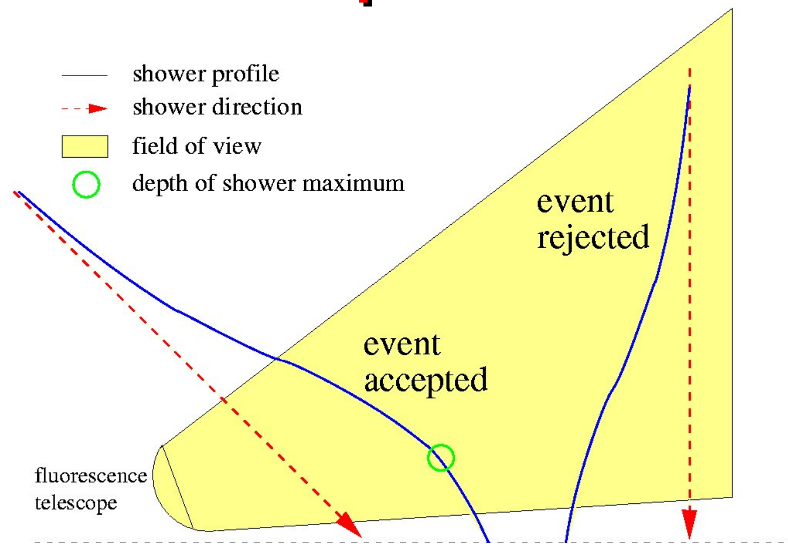
Auger/HiRes/TA compatible within their energy scale systematic uncertainties

Results

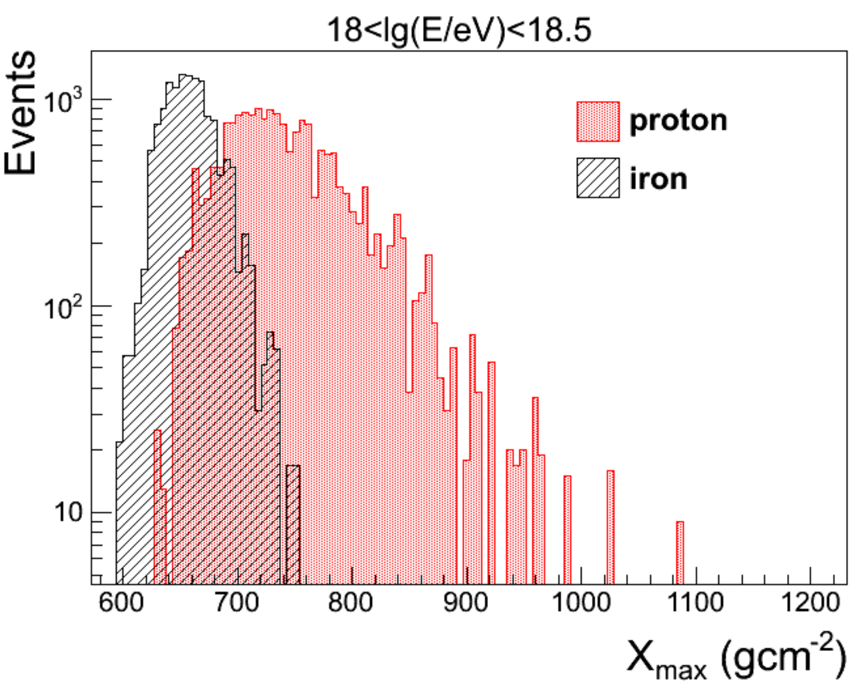
- Energy spectrum
- **Mass composition**
- Astrophysics
- Search for photons and neutrinos
- Hadronic interactions

Observation of longitudinal profile





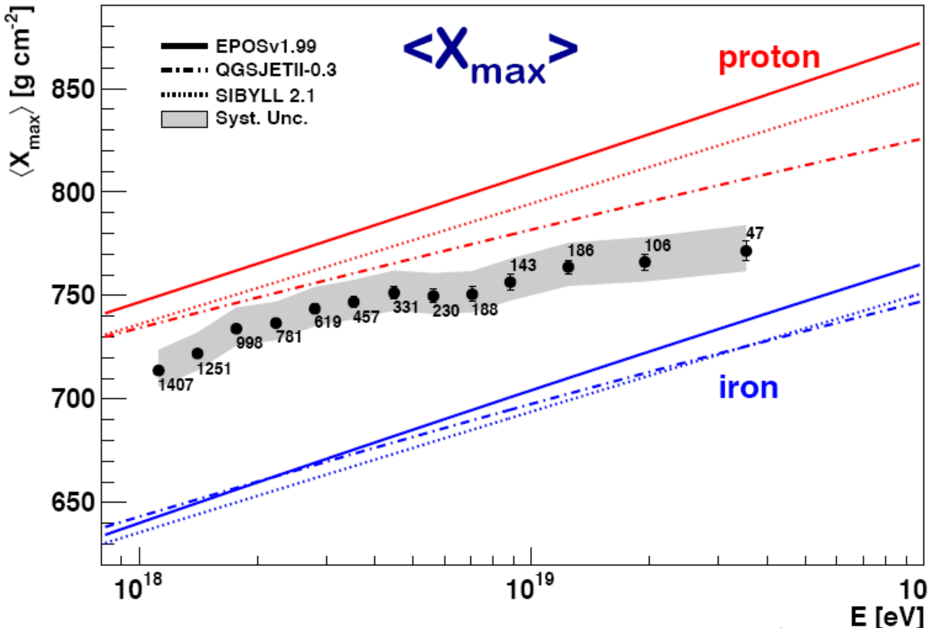
$$<X_{max}> = \alpha(\ln E - <\ln A>)+\beta$$

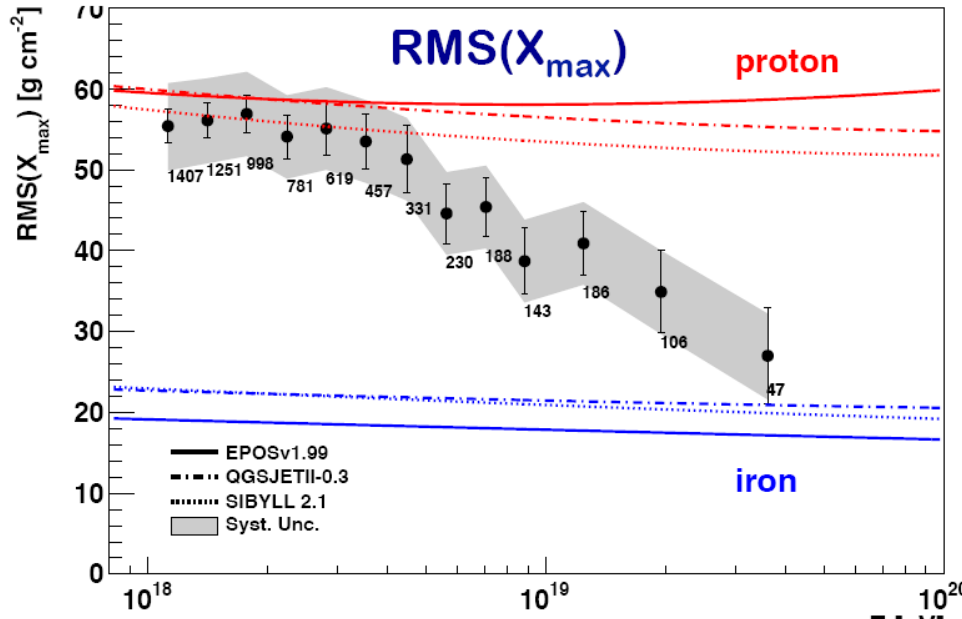


<Xmax> and its RMS
- sensitive to mass composition
- key observables for composition studies

Mass Composition: mean X_{max} and its RMS

G. Pinto, P.Facal @ **ICRC 2011,** The Pierre Auger Coll. arXiv 1301.6637, to appear on JCAP





Syst uncertainty < 13 g cm^{-2}

Xmax resolution ~ 20 g cm^{-2}

6744 hybrid events (Dec 2004 – Sept 2010) E > 10^{18} eV
break of the elongation rate at around 2.4 10^{18} eV (close to the ankle)

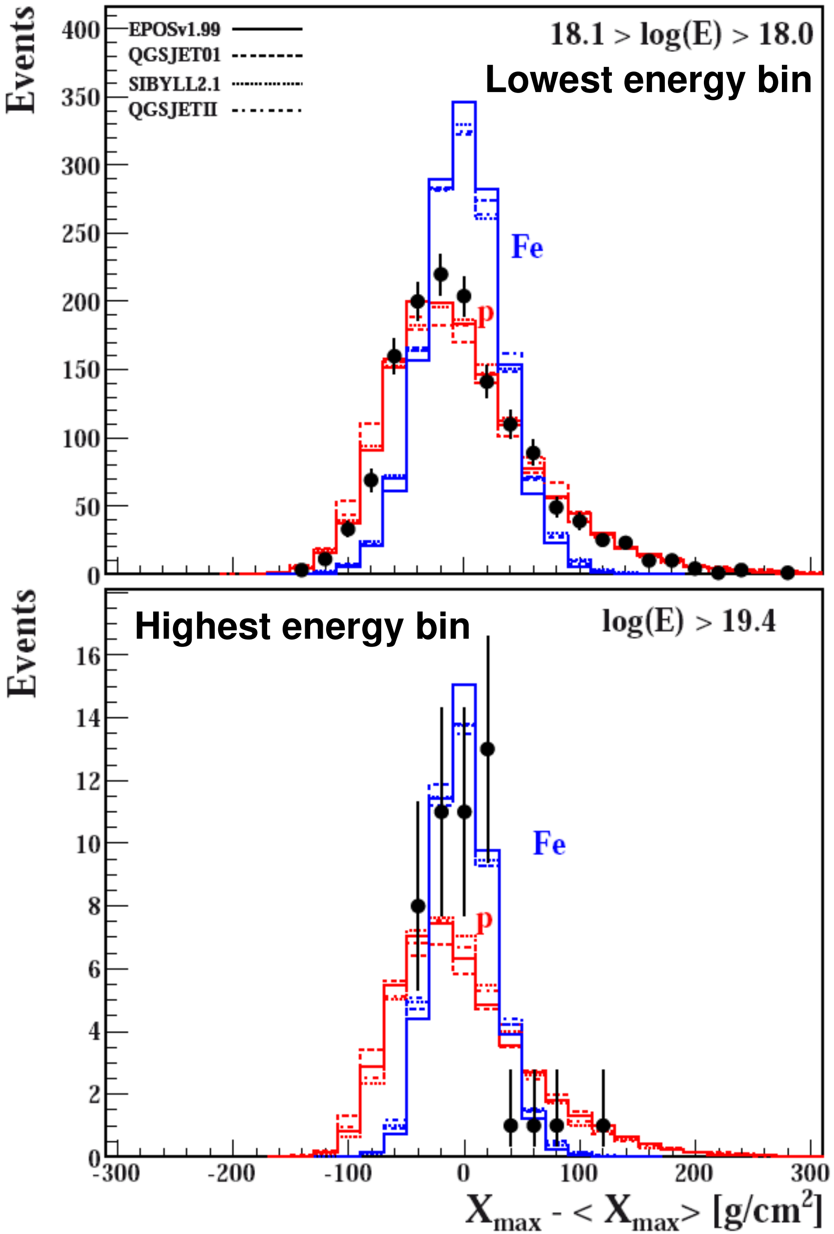
Xmax distributions become narrower with energy

→ increase of the mean mass with the energy

→ interpretation depends on hadronic interaction models

Distributions shapes

P.Facal @ **ICRC 2011**



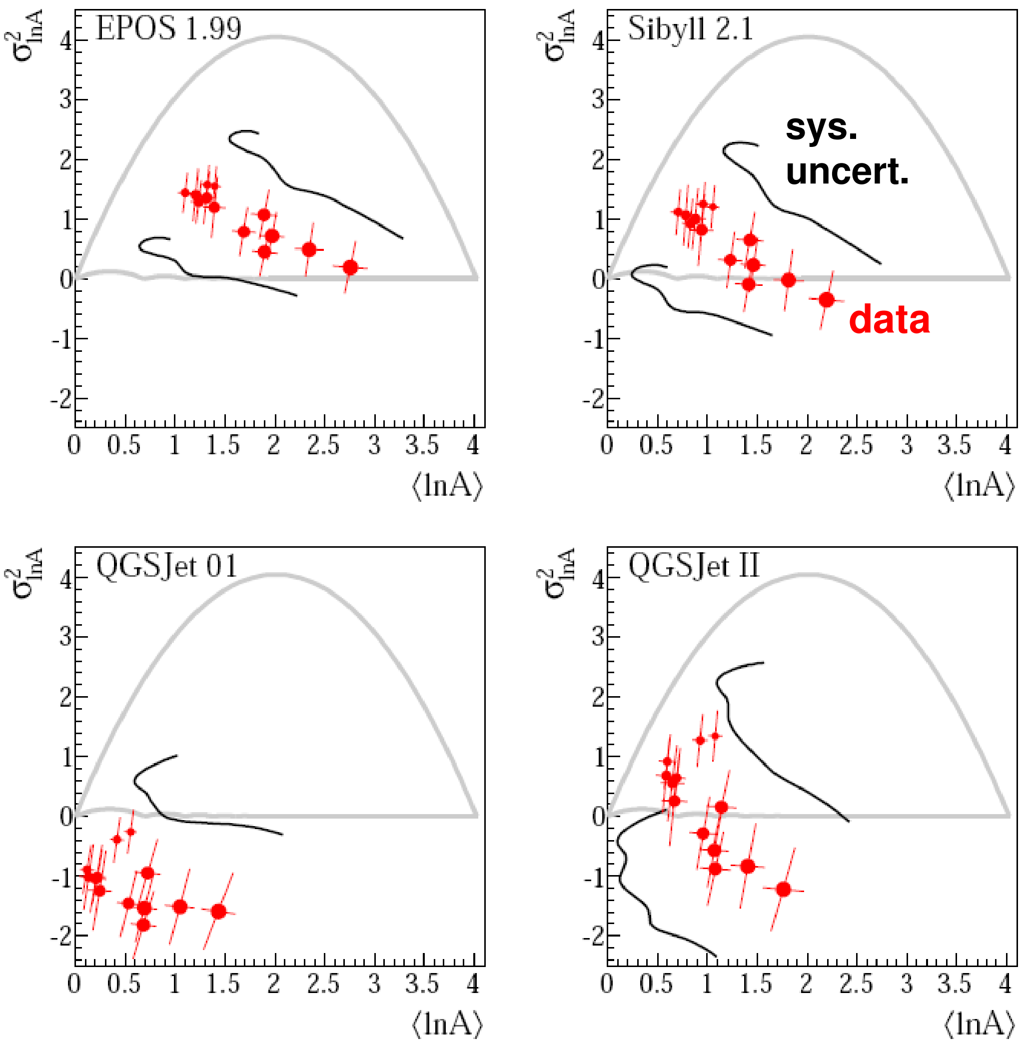
Subtracting <Xmax> allows a comparison of the shapes

At low energy:
- shape compatible with a very light or mixed composition

At high energies:
- narrower shape, significant fraction of nuclei (CNO or heavier)

Mass composition: interpretation

The Pierre Ayger Coll. arXiv 1301.6637, to appear on JCAP



$$\langle \ln A \rangle = \frac{\langle X_{\max} \rangle - \langle X_{\max} \rangle_p}{f_E}$$

measured

model dependent

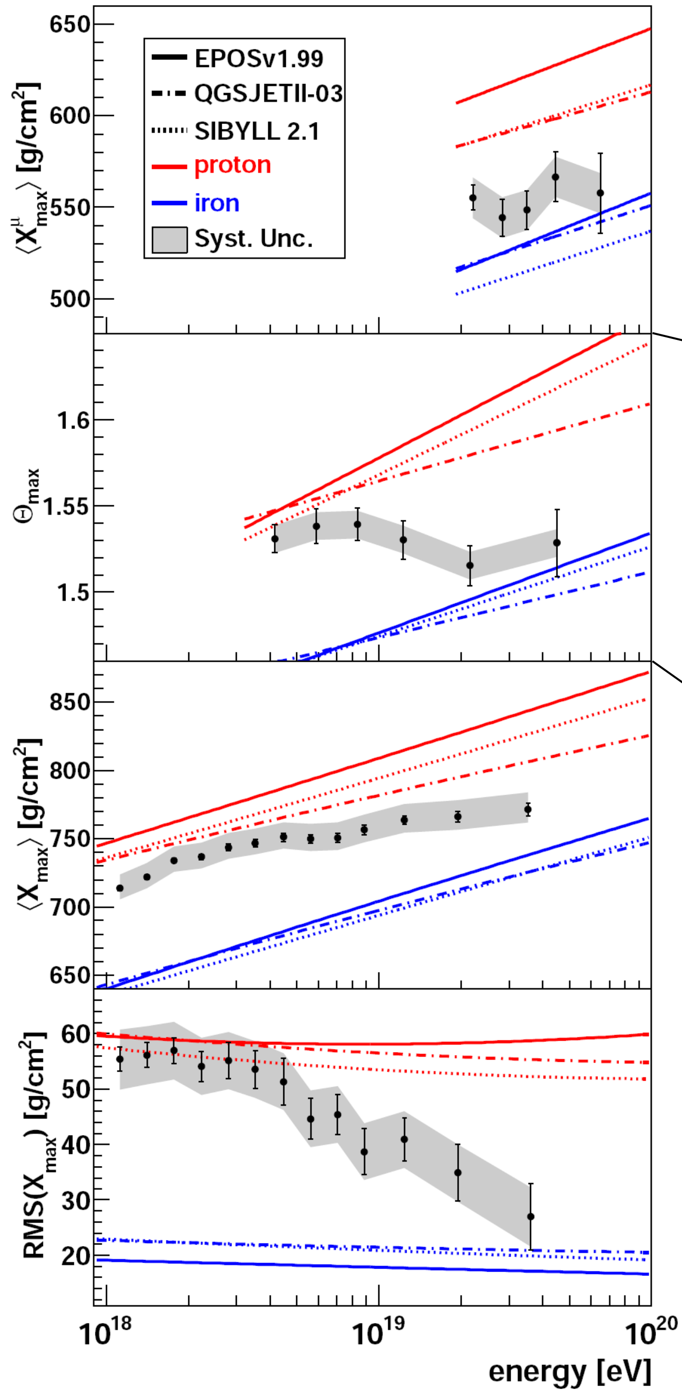
$$\sigma^2_{\ln A} = \frac{\sigma^2(X_{\max}) - \sigma^2_{\rm sh}(\langle \ln A \rangle)}{b\ \sigma_p^2 + f_E^2}$$

Decreasing dispersion of lnA

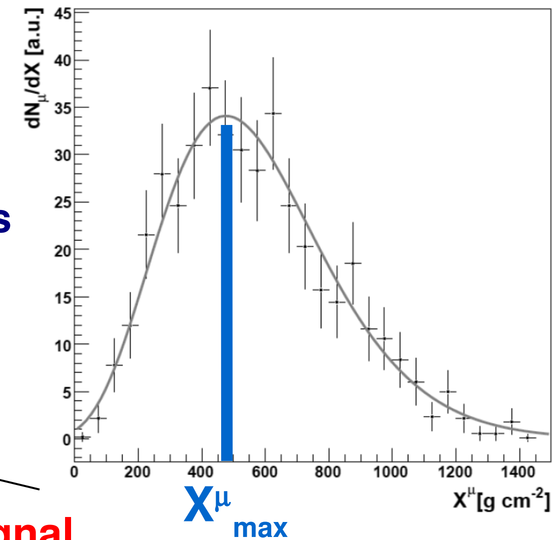
Pure proton (excluded at the highest energy by Auger data)

Nearby source (<100 Mpc) or harder injection spectra

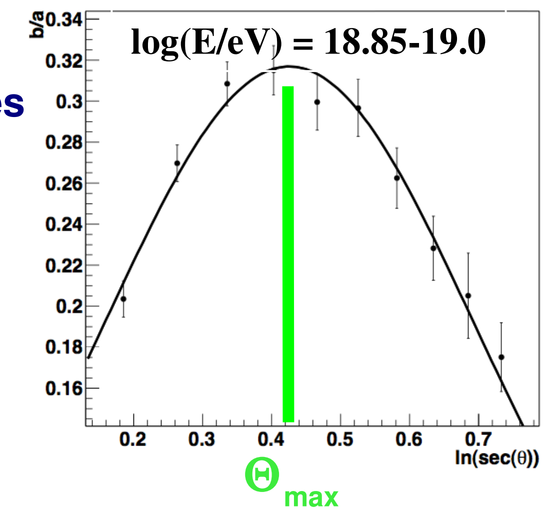
Test of the models: none rejected with current systematic uncertainty



Muon Production Depth
events with 55<zenith<65
E> 20 EeV
r >1.8 km from shower axis
use muon arrival time differences



Azimuthal asymmetry in SD signal
events with 30<zenith<60
E> 20 EeV
0.5 <r < 2 km from shower axis
use asymmetry of rise times

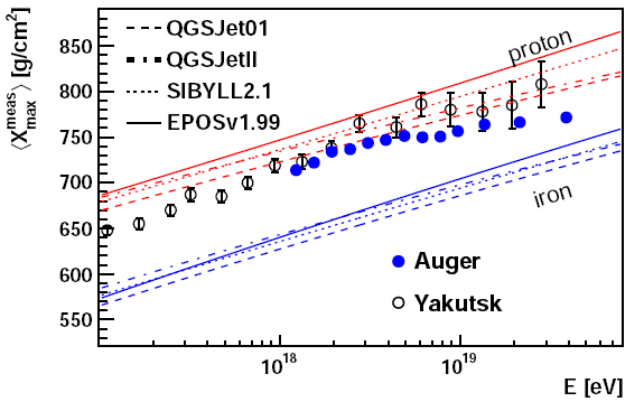


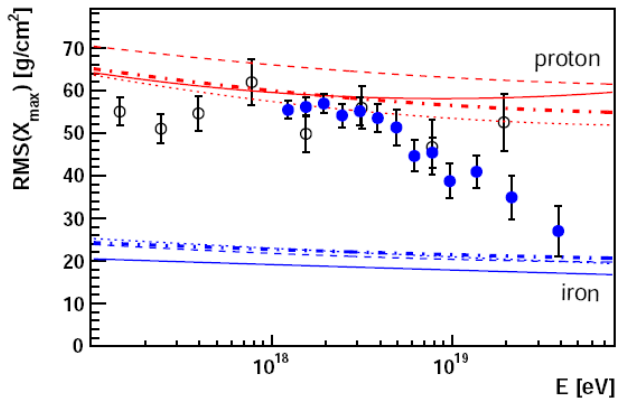
<Xmax> from FD

RMS of Xmax from FD

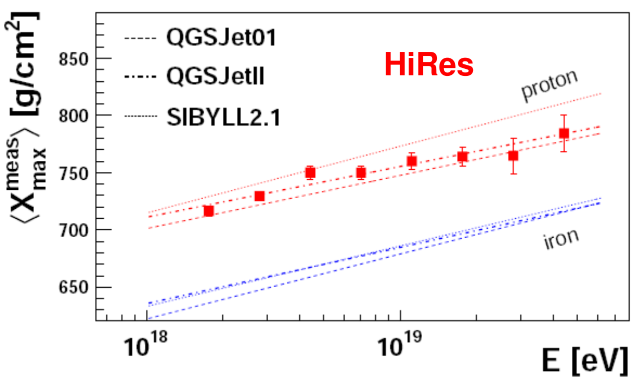
Mass composition: comparison

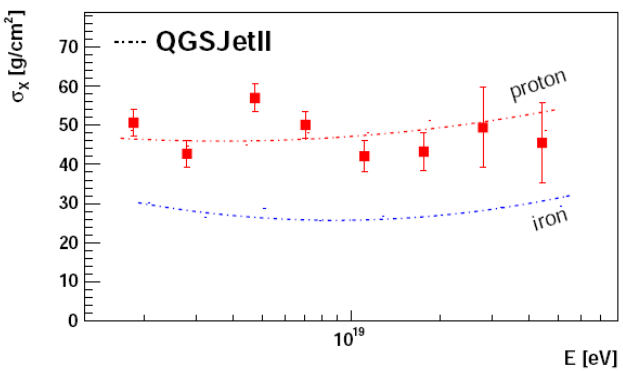
J. Bellido et al. @ **UHECR12**





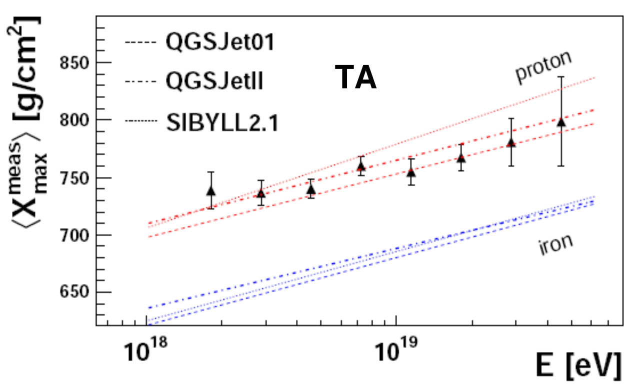
Auger/Yakutsk and HiRes/TA measure "different" $\langle X_{max} \rangle$





$\langle X_{max} \rangle$ quoted sys. uncertainties

Auger	±12 g cm^{-2}
HiRes	±6 g cm^{-2}
TA	±12 g cm^{-2}
Yakutsk	±20 g cm^{-2}



→ Auger/TA/Yakutsk compatible within systematic uncertainty

→ Auger and HiRes results not compatible at E>$10^{18.5}$ eV

Data in the Northern Hemisphere indicate constant light composition but can not exclude the Auger scenario. More data needed.

Results

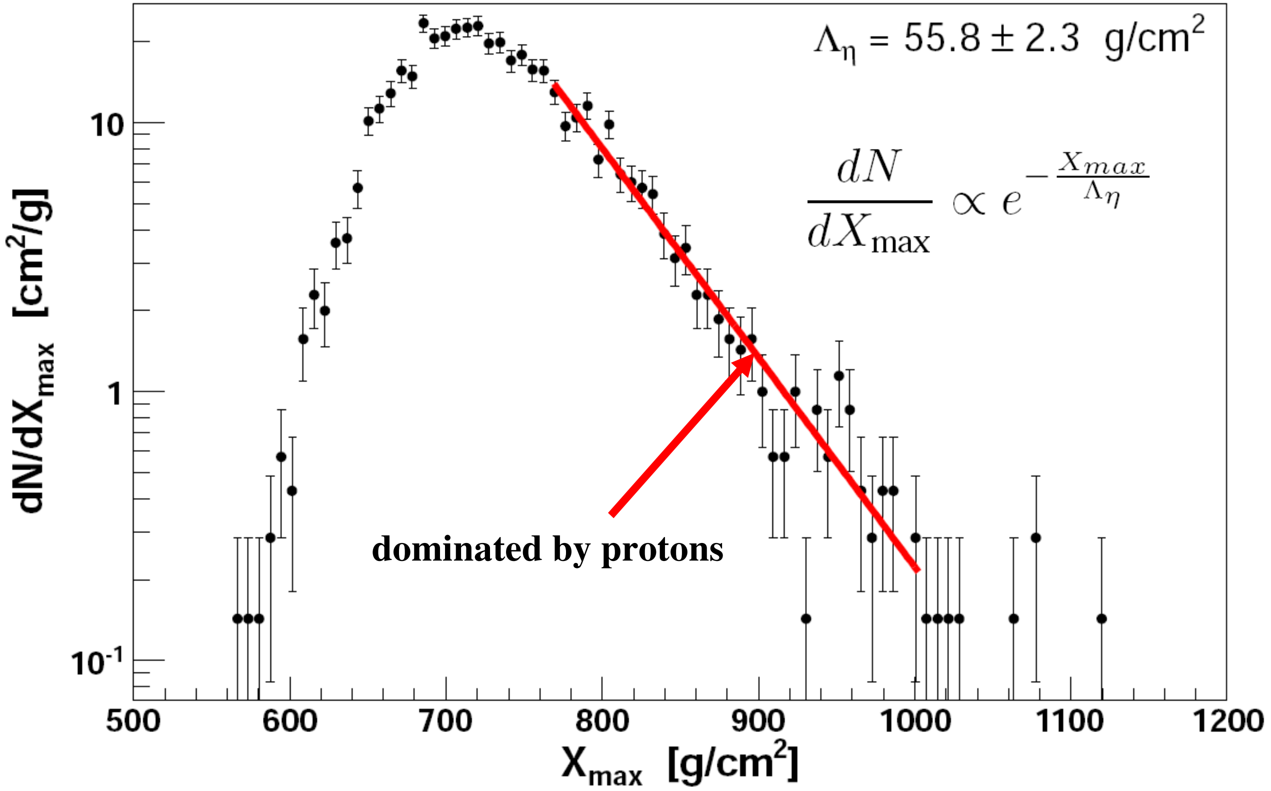
- Energy spectrum
- Mass composition
- **Hadronic Interactions**
- Astrophysics
- Search for photons and neutrinos

Measurement of the p-air cross-section

Tail of the distribution of X_{max} sensitive to cross-section

Fly's Eye → Ellsworth et al. Phys. Rev. D26 (1982) 336
Baltrusaitis et al. Phys. Rev. Lett. 52 (1984) 1380

$18 < \log_{10}(E/eV) < 18.5$



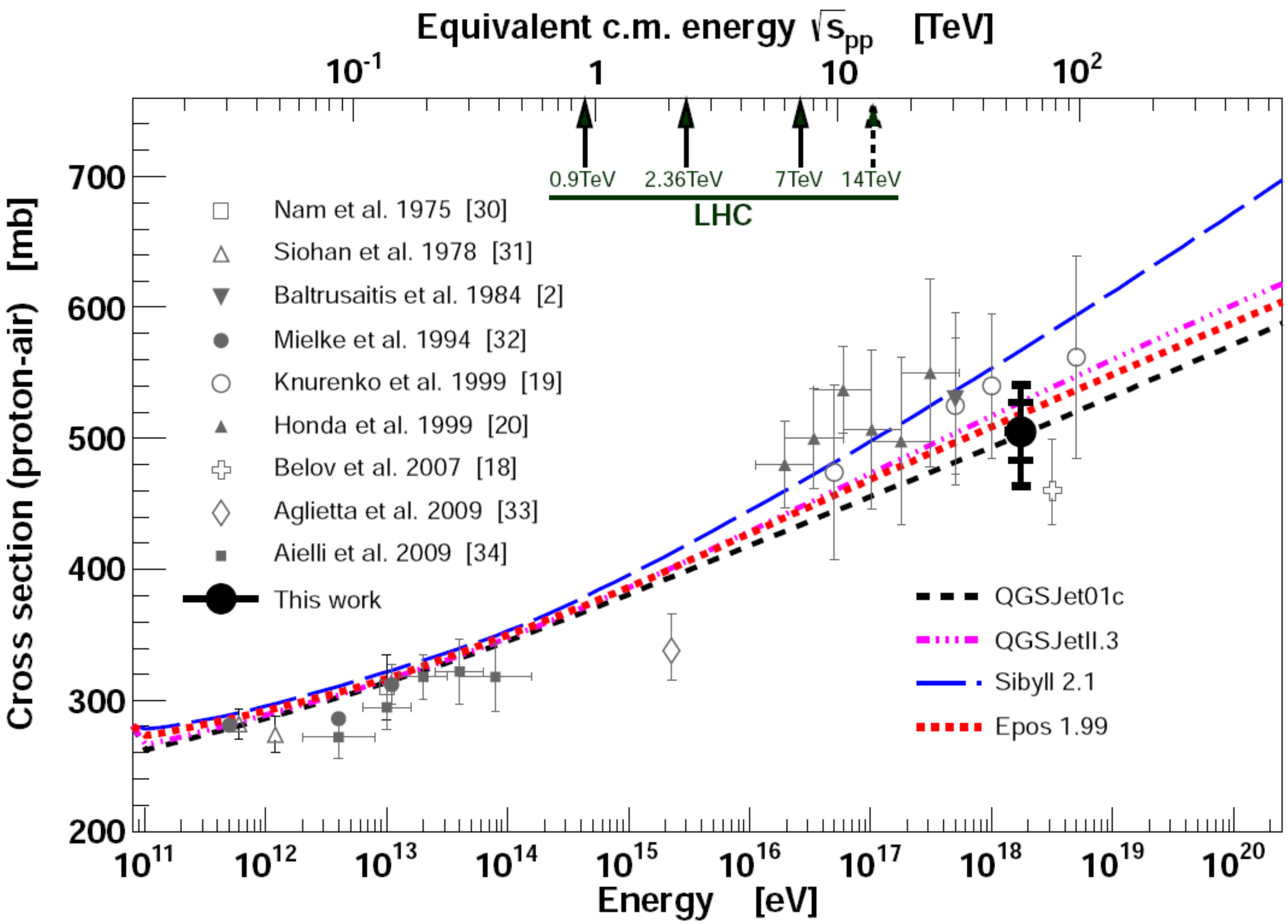
The Pierre Auger Collaboration, Phys. Rev. Lett. 109, 062002 (2012)

η is the fraction of "deepest" event from the unbiased X_{max} distribution

Why η = 20% ?
25% helium contamination produces a bias at the level of the statistical uncertainties

Use simulations to correlate Λ_η^{MC} with cross-sections

Λ_η^{MC} adjusted to reproduce the measured Λ_η



Energy well above the LHC measurements

Systematic Uncertainties

- **hadr. Models up to 19 mb**
- **energy scale 7 mb**
- **Λ_η systematics 15 mb**
- **conversion of Λ_η 7 mb**

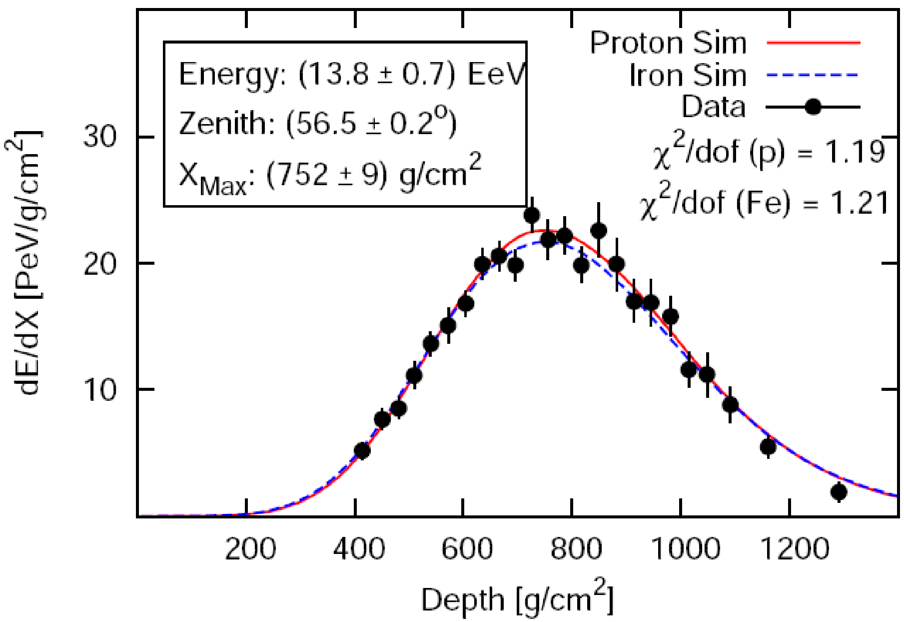
$< E > \sim 1.7$ EeV $\quad \sqrt{s} = 57$ TeV $\pm\ 0.3_{\text{stat}} \pm\ 6_{\text{sys}}$

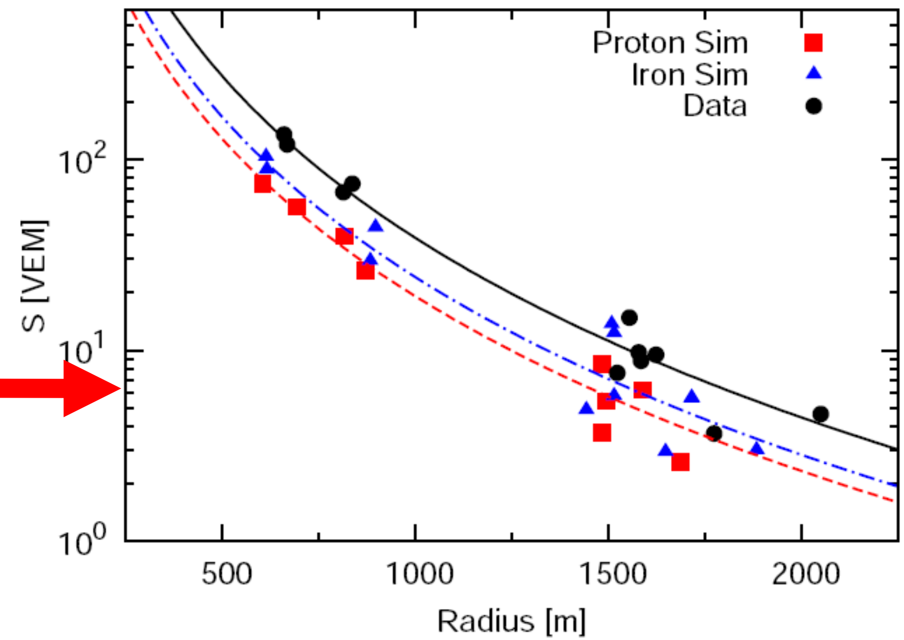
$$\sigma_{\text{p-air}} = (505 \pm 22_{\text{stat}}\ (^{+28}_{-36})_{\text{syst}})\ \text{mb}$$

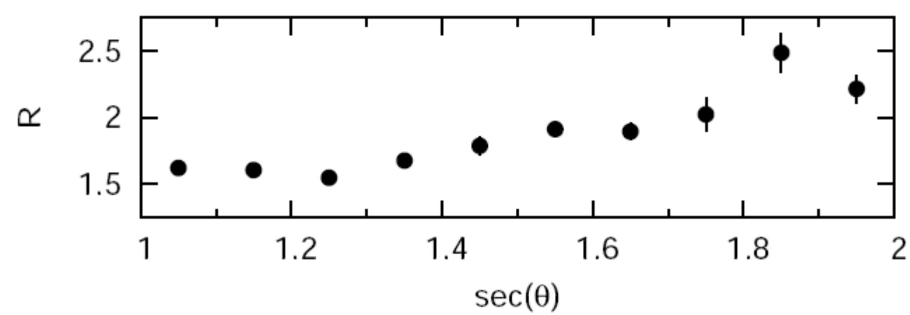
Additional Uncertainties due to diverse contaminations:

- photon fraction 0.5% +10 mb
- helium fraction 10% -12 mb
- **helium fraction 25% -30 mb**

Muon puzzle....







-more muons in data than in simulation

- zenith dependent effect

Not easy to reproduce data with current models

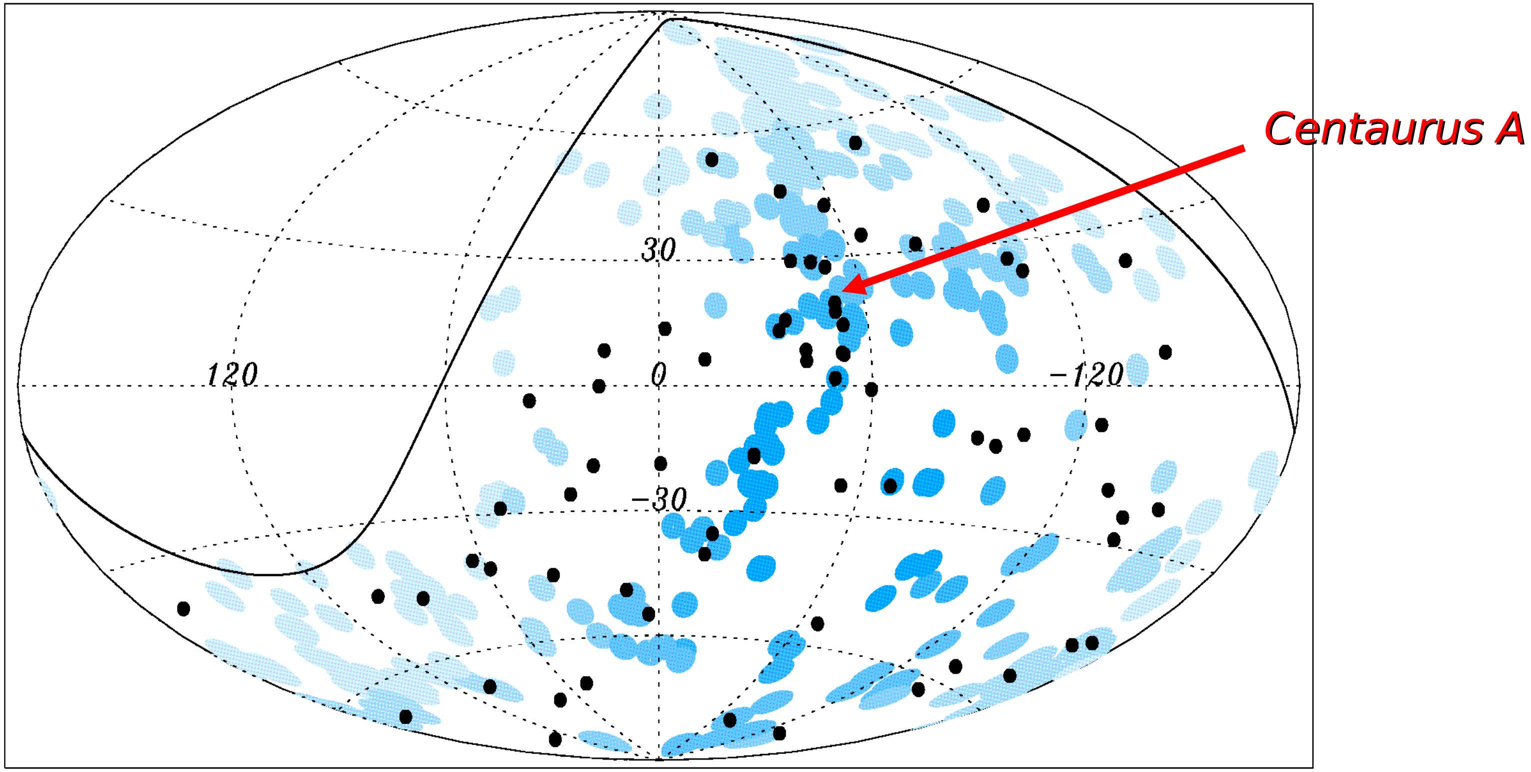
Results

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

Anisotropy at the highest energy

Astropart. Phys. 34 (2010) 314

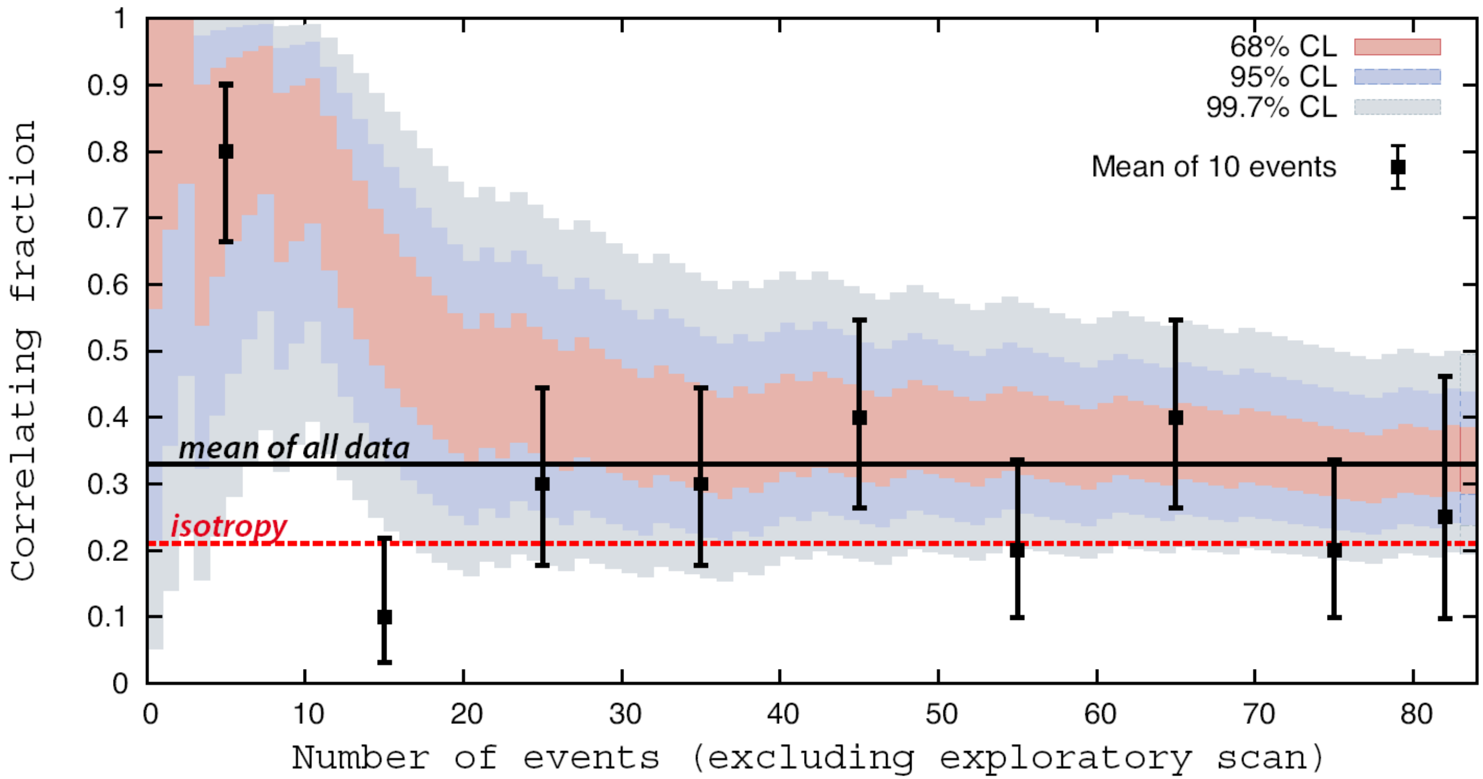
Jan 2004
Dec 2009



The 69 events with Energy > 55 EeV detected by the Pierre Auger Observatory
Blue circles of radius 3.1° centered at the positions of the 318 AGNs < 75 Mpc in the VCV catalog. The exposure-weighted fraction of the sky covered by the blue circles is 21% (fraction of correlating events under the hypothesis of isotropy)

Limitations of the catalogue: incomplete and inhomogeneous

Degree of correlation



Updated to June 2011

k/N (28/84) = 0.33

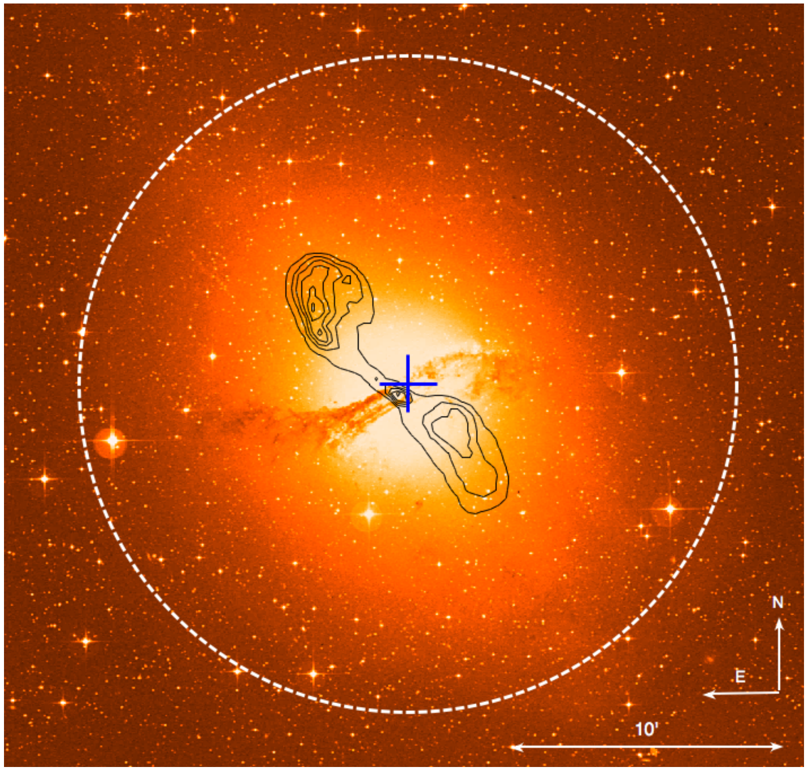
Degree of correlation p_data = k/N vs total number of time-ordered events:
the 68%, 95% and 99.7% confidence level intervals around the most likely value are shaded.
The isotropic value is p_iso = 0.21. The current estimate of the signal is 0.33 ± 0.05.
The black symbols show the correlation fractions bins of independent 10 consecutive events

Chance probability for a isotropic source distribution < 1%

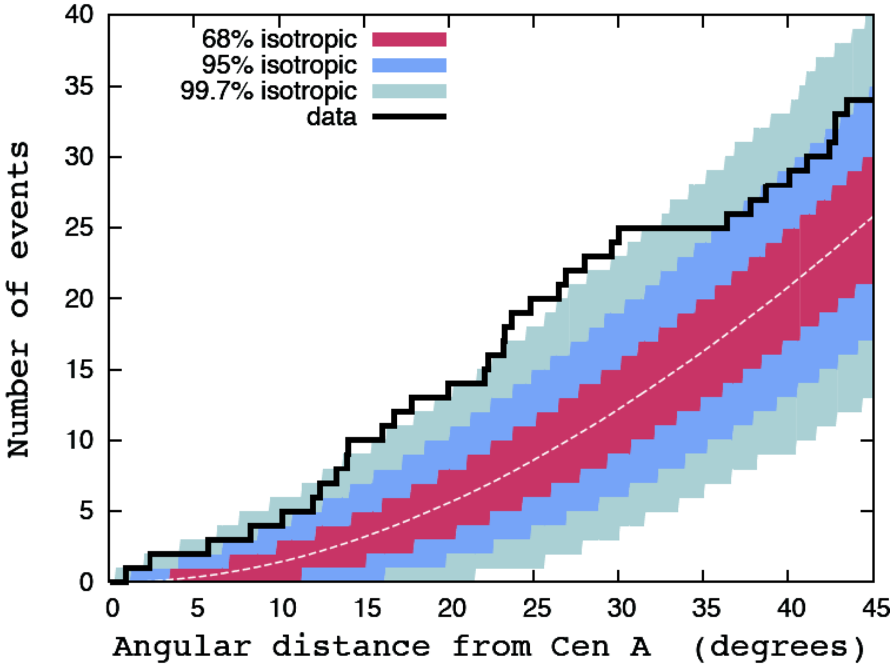
TA: similar analysis (arXiv:1205.5984v1), northern Hemisphere, 20% AUGER exposure
k/N (11/25) = 0.44 p_{iso} = 0.24 chance prob ~ 2%

Centaurus A

Astropart. Phys. 34 (2010) 314



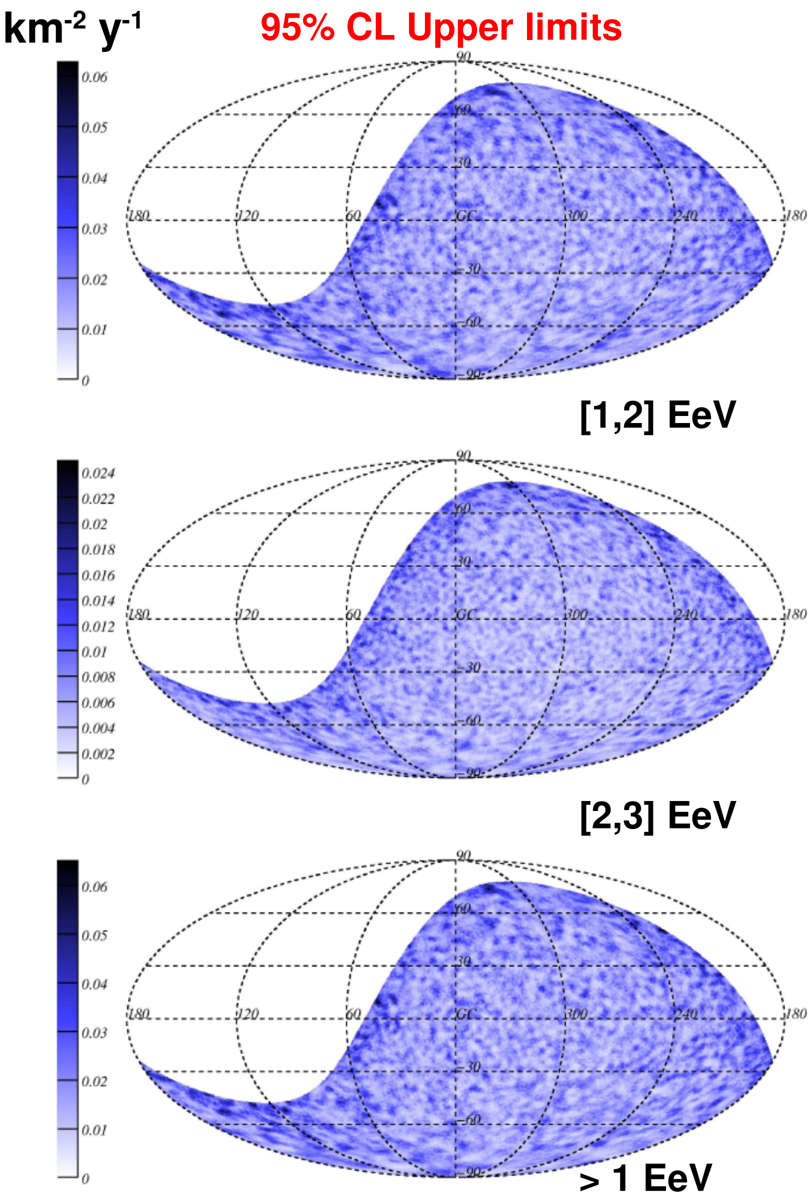
CEN A: optical image, radio contours (VLA), VHE best fit position and 95% C.L. (HESS). From http://arxiv.org/pdf/0903.1582v1



Cumulative number of events with energy E>=55 EeV as a function of angular distance from the direction of Cen A.

Maximum deviation from isotropy at 24°
19 observed vs 7.6 expected
Li-Ma 3.3 sigma

Search for point sources of EeV neutron



The Pierre Auger Coll., ApJ, 760 (2012) 148

AUGER has sensitivity to galactic neutron sources

mean decay length @ 1 EeV ~ 10 kpc

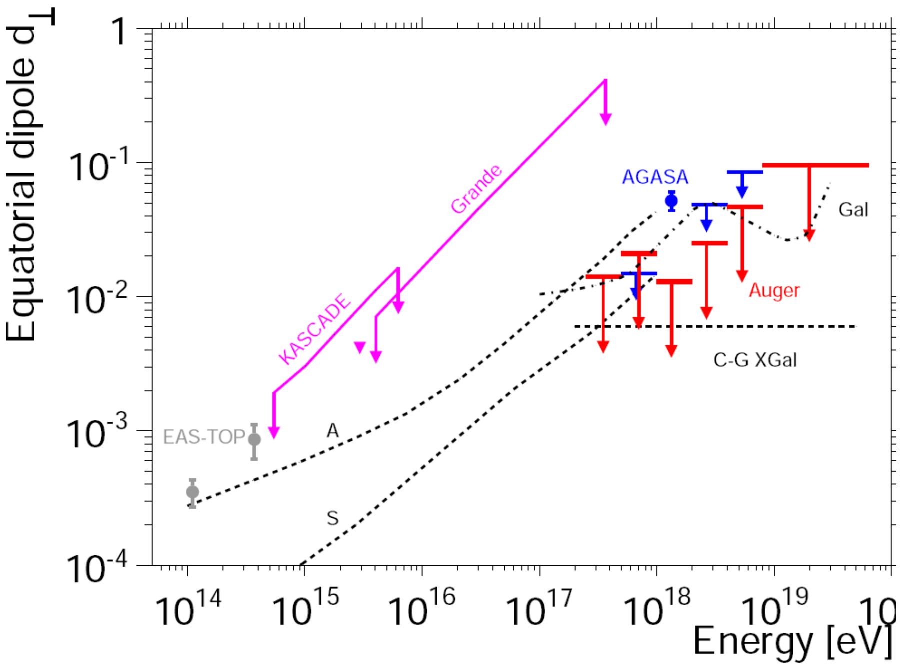
Along the galactic plane

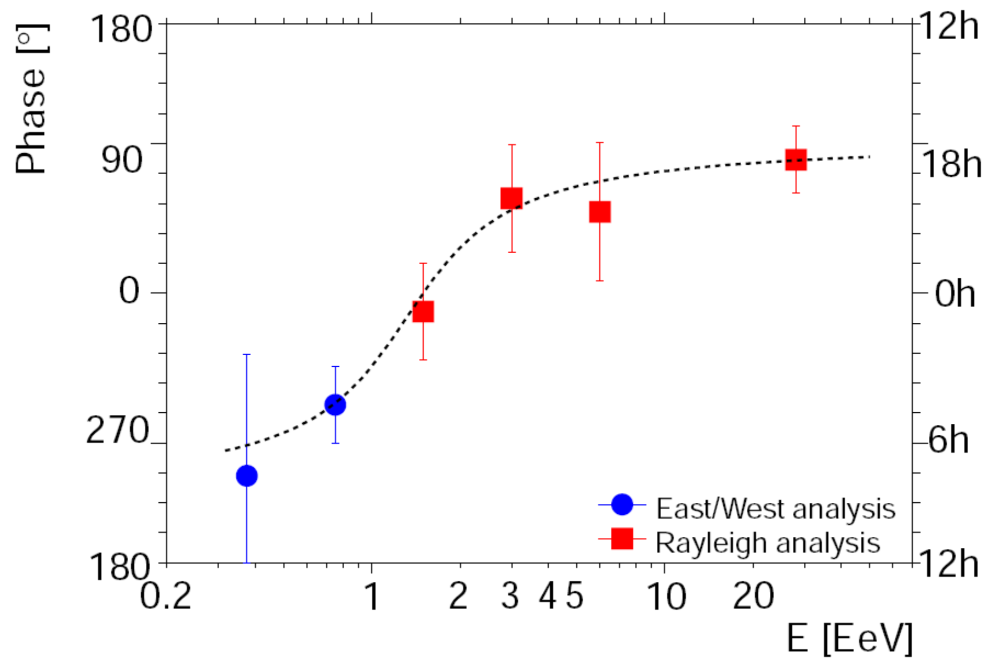
0.024 km^{-2}y^{-1} [1,2] EeV
0.014 km^{-2}y^{-1} [2,3] EeV
0.026 km^{-2}y^{-1} > 1 EeV

No excess found

Search also performed on galactic sources from Fermi LAT and HESS catalogs

Large scale anisotropy





Upper limits on equatorial dipole component

Phase of first harmonic

Predictions of models for anisotropy due to galactic or extra-galactic cosmic rays in reach

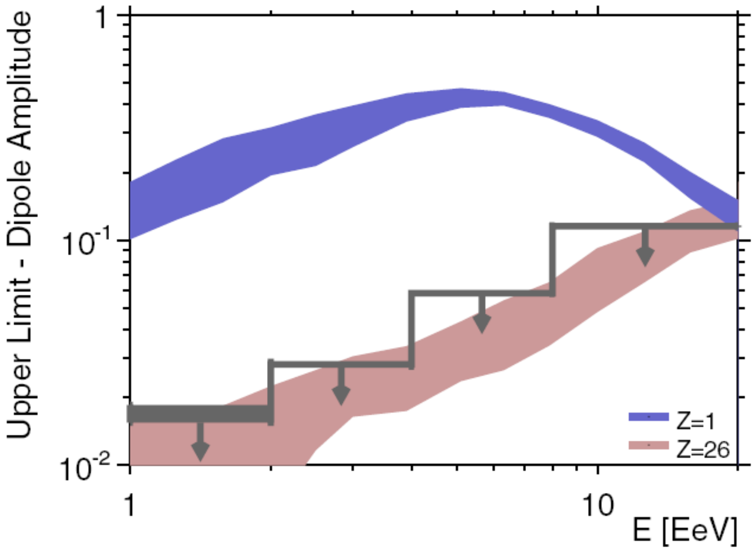
P ~ 10^{-3} of observing this transition from an isotropic distribution

no a priori search -> no confidence level

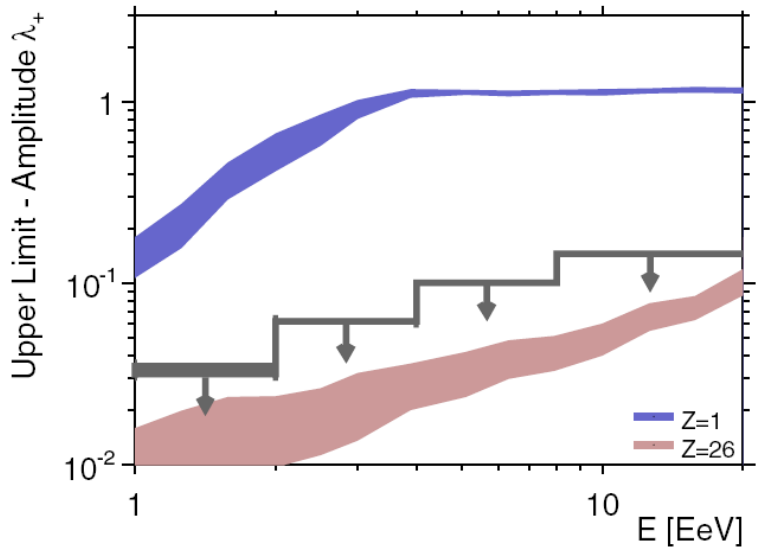
Large scale anisotropy: implications

The Pierre Auger Coll. **ApJL 762 (2012) L13**

dipole



quadrupole



Prediction from stationary galactic sources

Scenario of stationary galactic sources emitting light particles in all directions disfavored

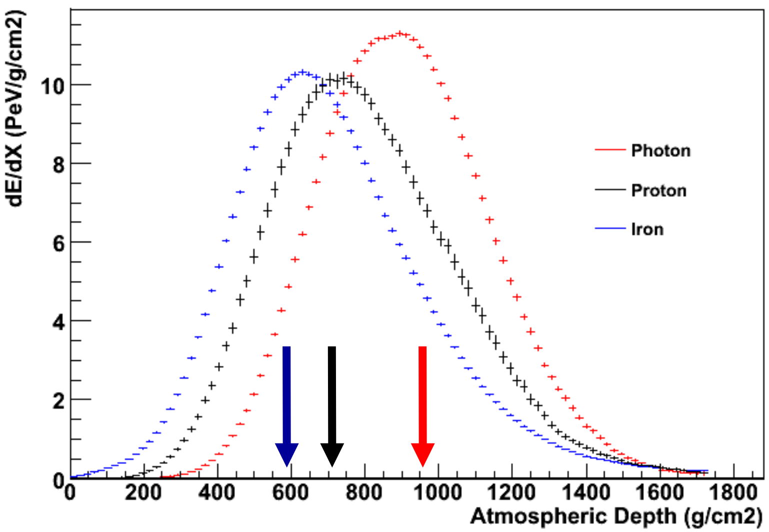
EeV region

a mixture of galactic heavy elements with extragalactic light elements is allowed

Results

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

Search for photon primaries

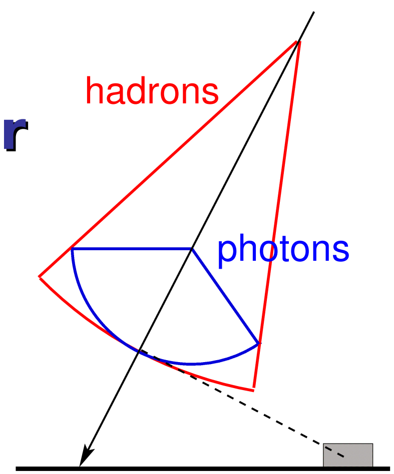


Photon showers develop deeper in the atmosphere

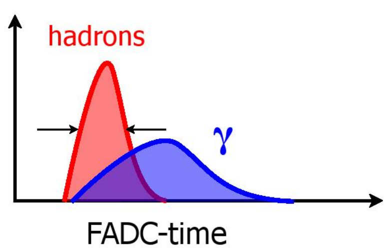
FD: search for events with deep Xmax

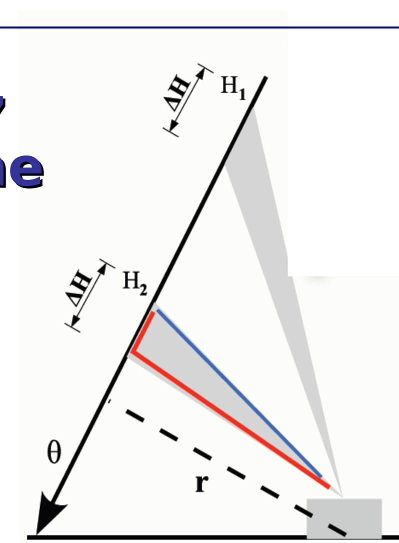
SD: search based on signal time structure

Deeper showers larger curvature

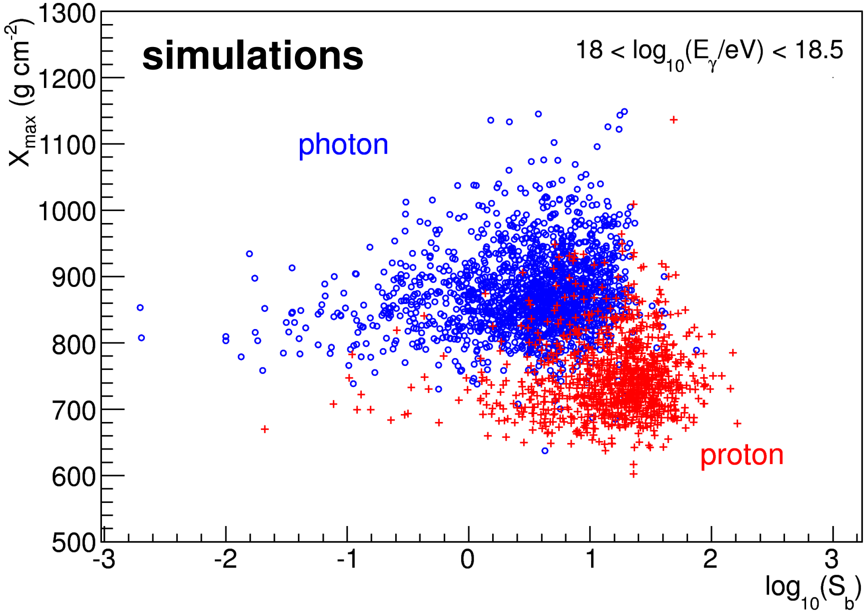


Slower signal, longer risetime





(hybrid) photon/hadron separation



signal amplitude

- deep shower

large X_{max} (from **FD**)

- structure of the LDF

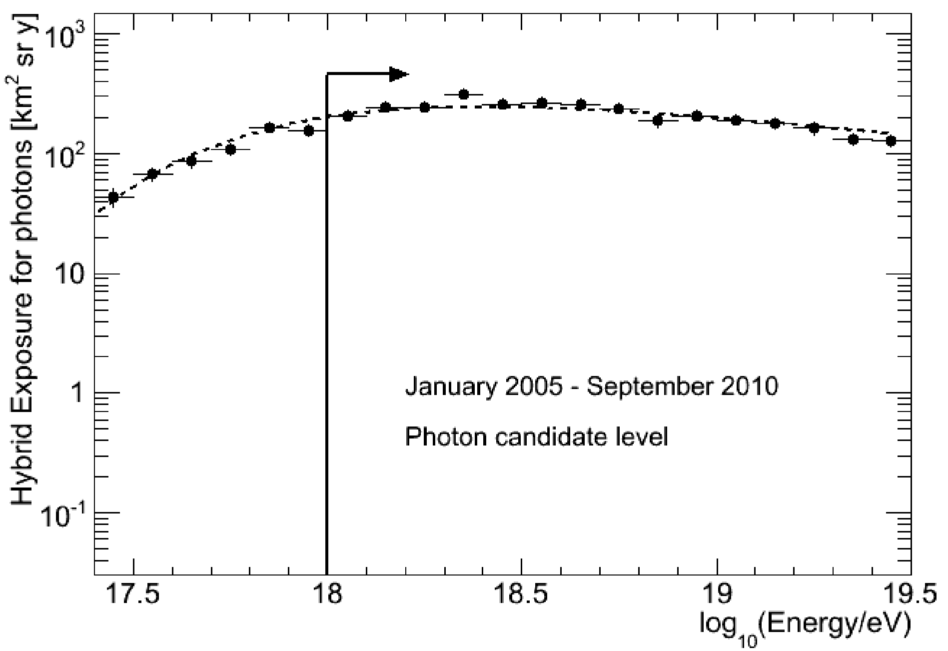
different time structure and smaller signal (from **SD**)

Realistic and time dependent

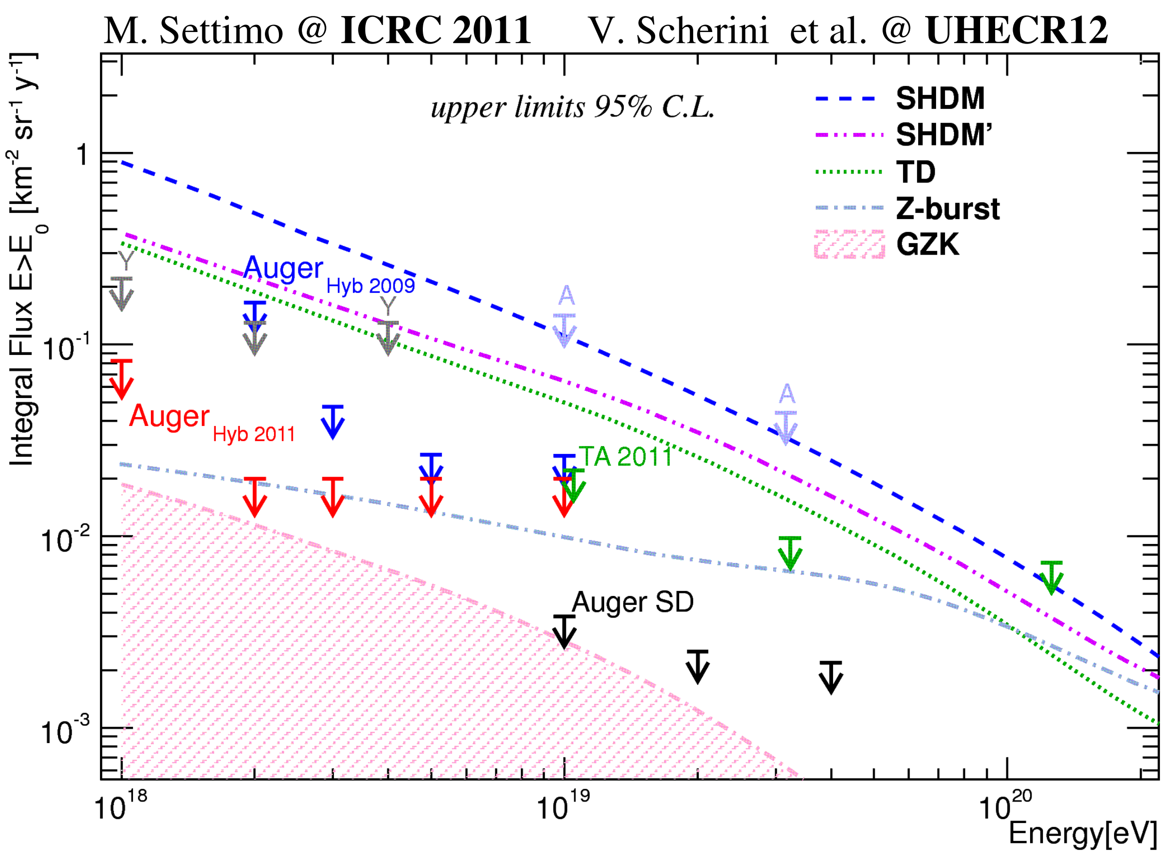
actual DAQ and atmospheric conditions taken into account (same approach used for the hybrid spectrum)

Proton background less than 1%

Hybrid Exposure for photons



Upper limit to the integral photon flux



Upper limits to the integral photon fraction assuming the Auger Spectrum

0.4%, 0.5%, 1.0%, 2.6% and **8.9%** for E> **1, 2, 3, 5 and 10 EeV**

Number of candidates
6, 0, 0, 0, and 0 for E> 1, 2, 3, 5 and 10 EeV

flux and fraction upper limits down to the EeV region

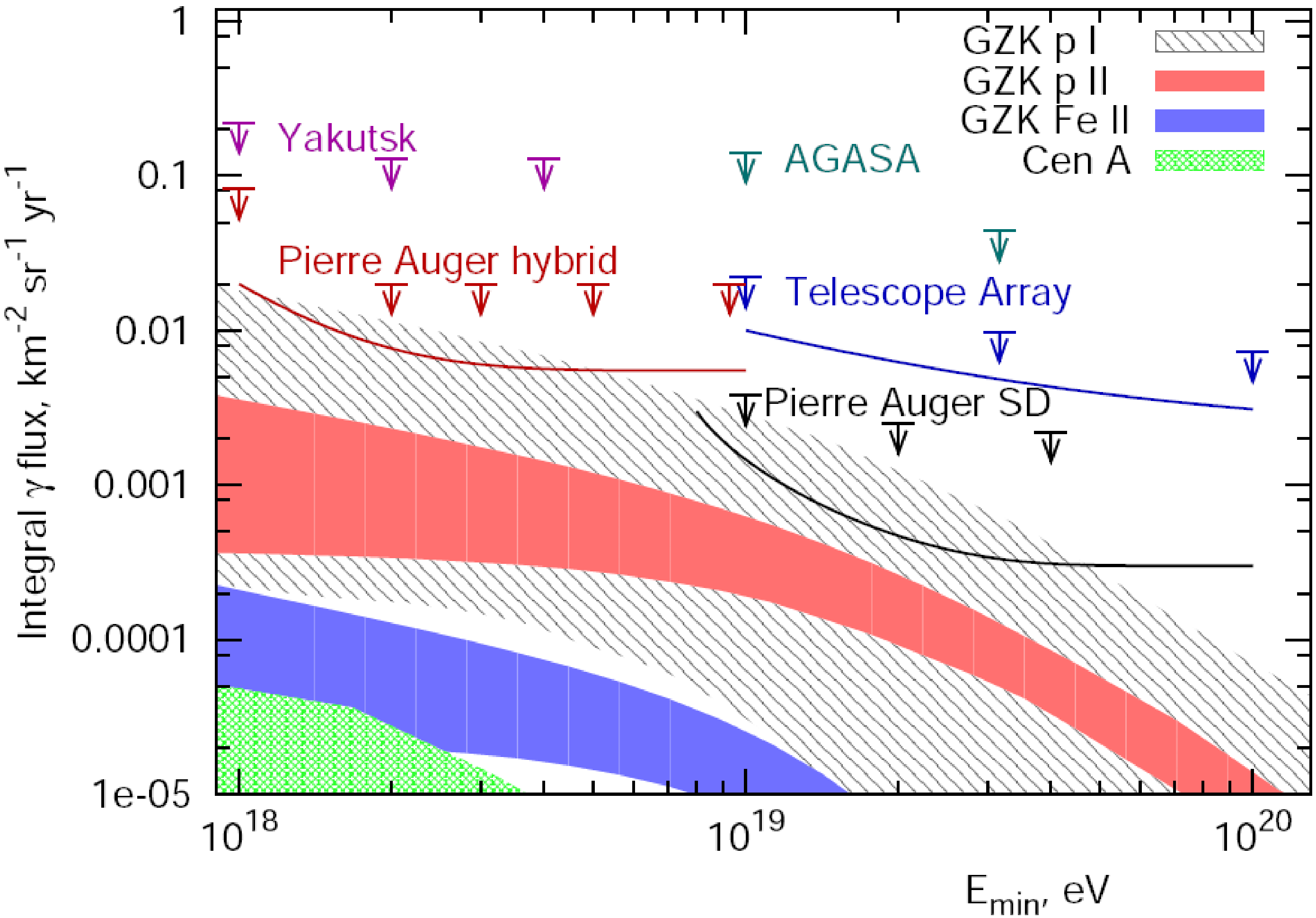
top-down models severely constrained

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

GZK region within reach in the next years

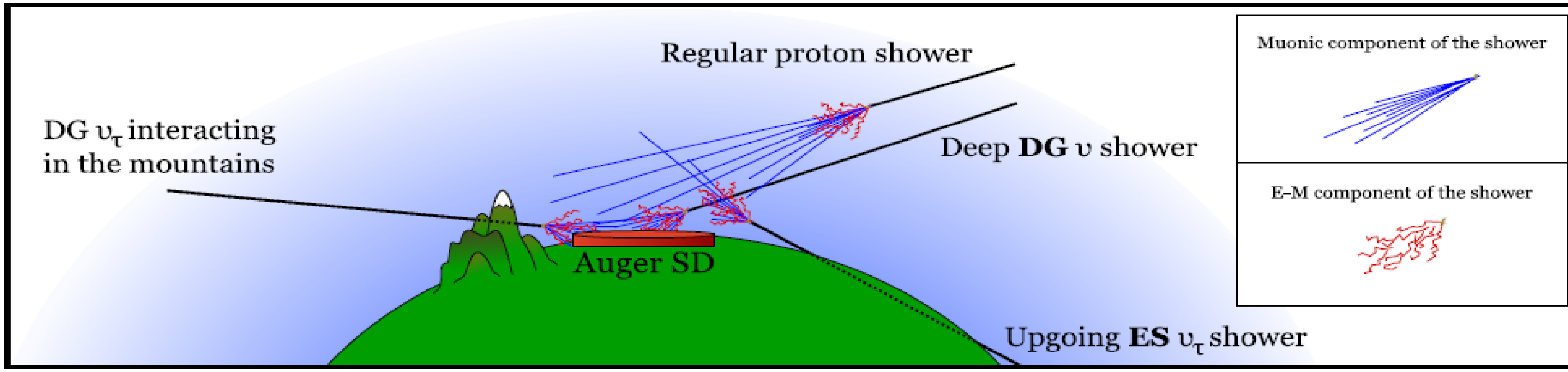
Future perspectives for photons search

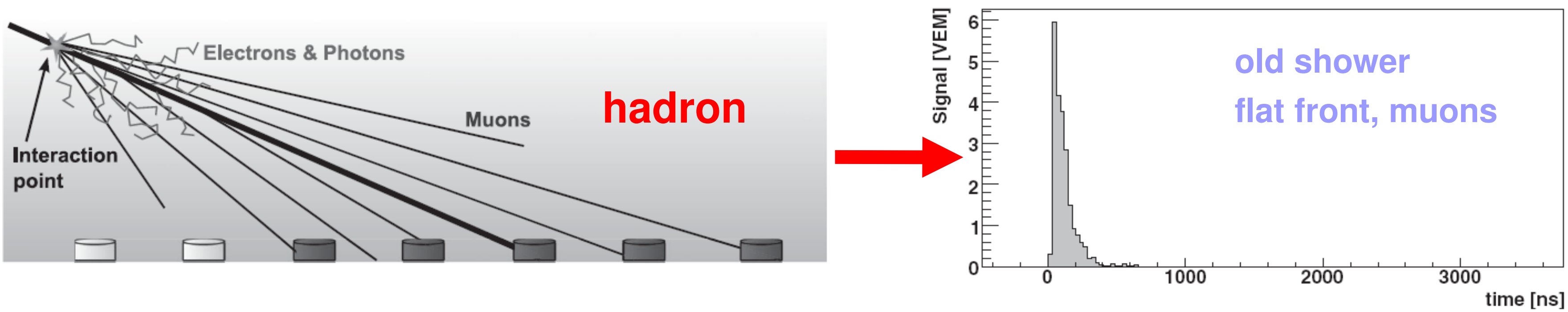
M.Risse et al. @ **UHECR 2012**

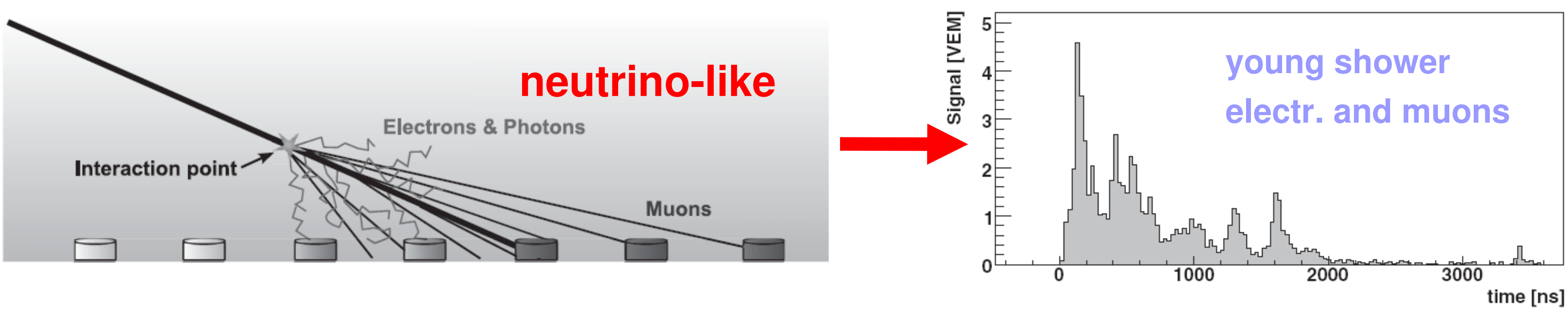


Solid lines: projected sensitivity at 2015

Search for neutrinos



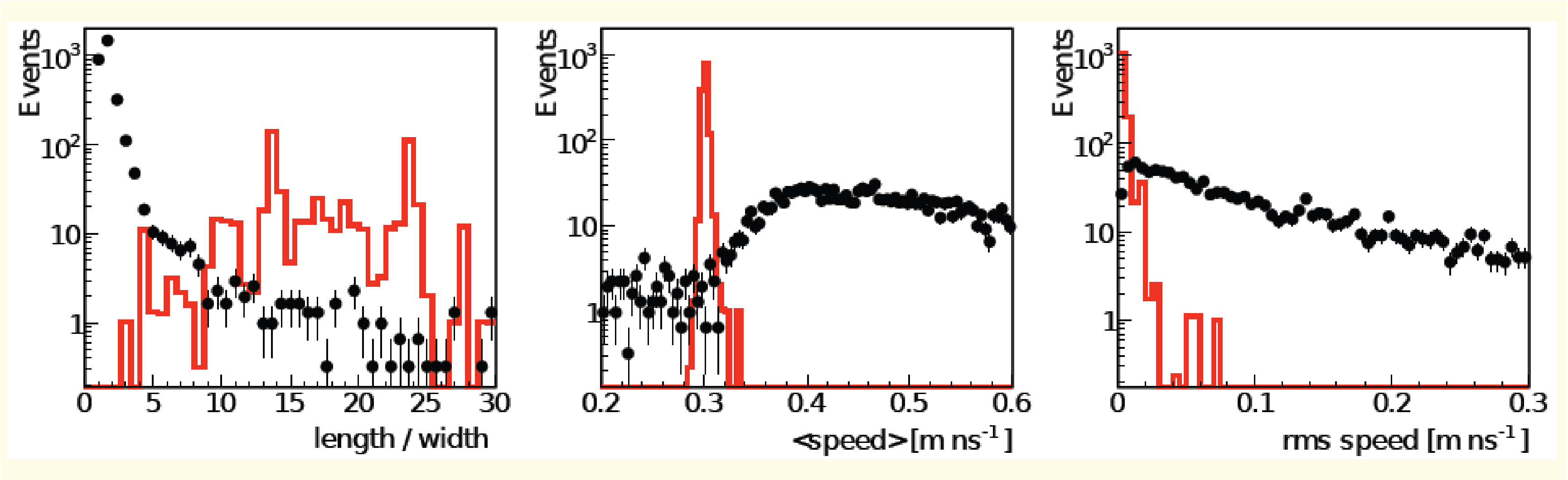




Important for neutrino detection: observable only if almost horizontal

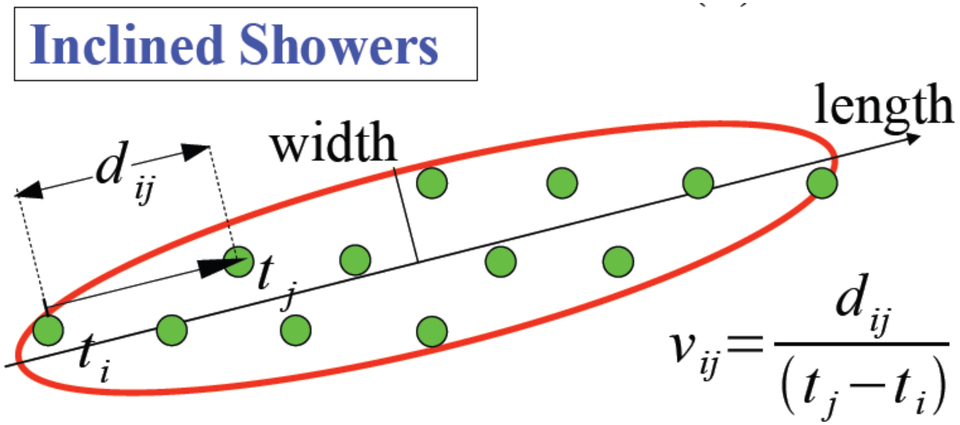
Neutrino signature: an inclined shower with large electromagnetic component

Neutrino-like event selection



Data

Simulated neutrino signal



Earth-skimming

Length/width >5

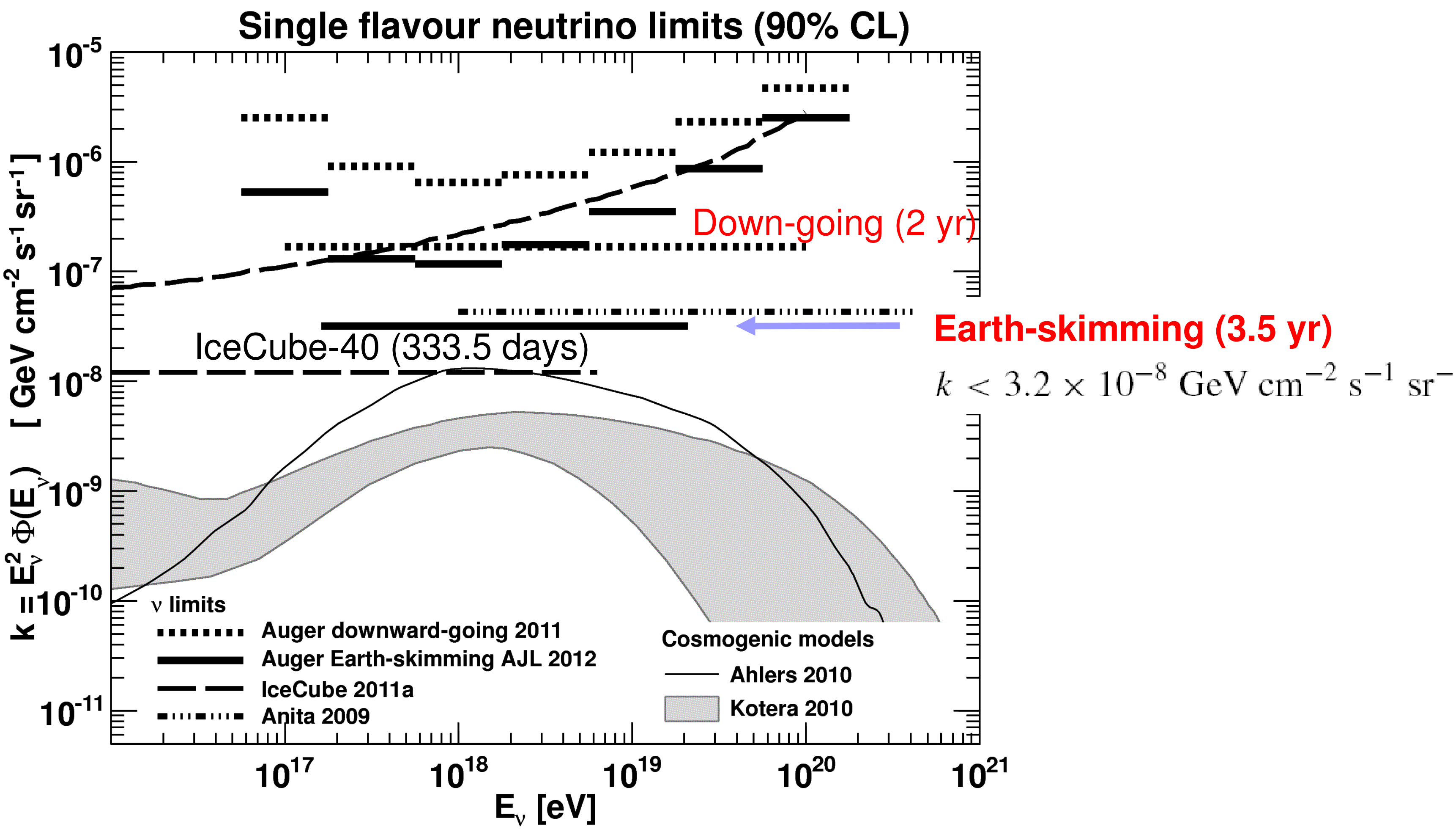
0.29< speed < 0.31 m/ns

rms< 0.08 m/ns

Similar selection rules for down-going

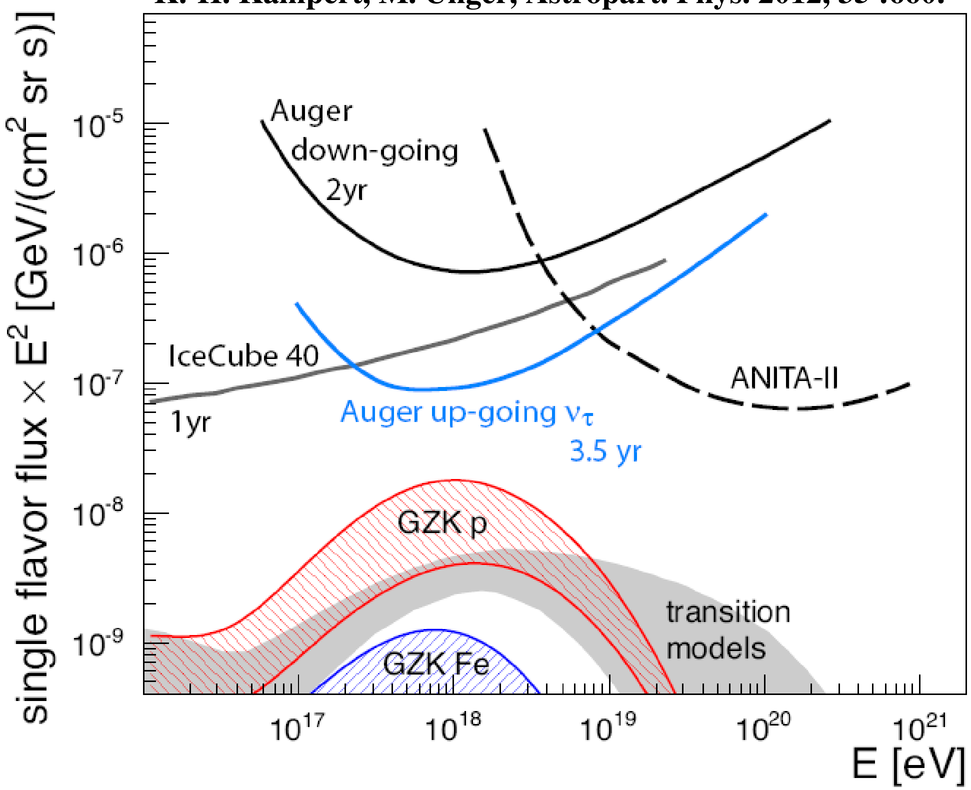
Upper limit on the diffuse neutrino flux

The Pierre Auger Coll., Astrophysical Journal Letters, 755 (2012) L4

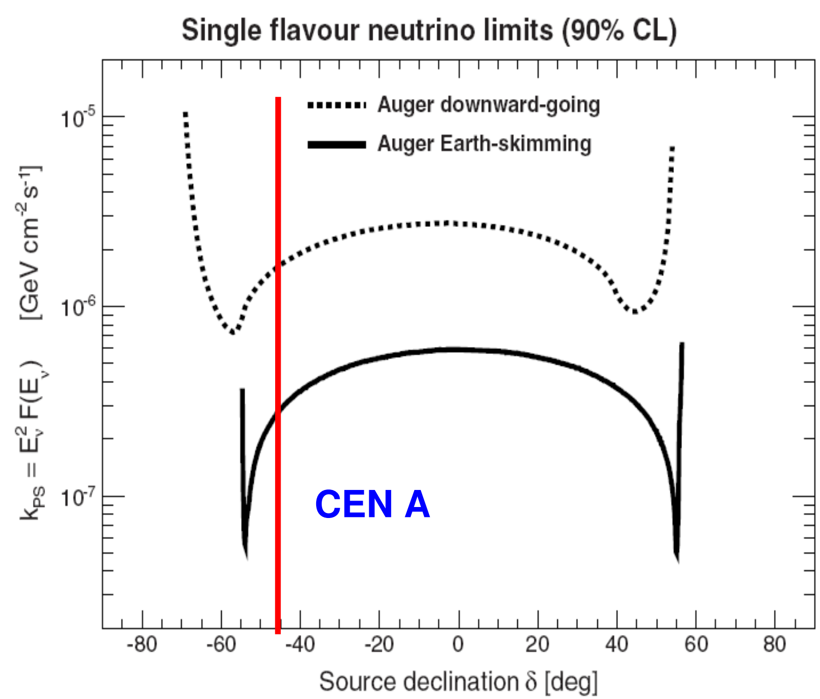


Search for neutrinos

K.-H. Kampert, M. Unger, Astropart. Phys. 2012, 35 :660.



Differential upper limits compared to other experiments and model predictions



Upper limits as a function of declination
high sensitivity close to the horizontal direction

Enhancements and test “laboratory”

Extension towards the lower energies

- improve detector performance at the transition to extragalactic component between ~10^{17} and 10^{18} eV (HEAT and AMIGA)
- cross calibration with other experiments

The Pierre Auger Observatory as an ideal site to test and develop new detection techniques

- Radio detection (AERA)
- Microwave detection (several projects)

Summary of results

Spectrum

- flux suppression established (E > 4 10^{19} eV)
- ankle observed at about 4 10^{18} eV

Composition

- mixed scenario: light dominated at low energies, heavier with increasing energy (interpretation is model dependent).
- **challenging (open) science case at the highest energy**

Hadronic interactions

- first measurement of proton-air cross-section at $\sqrt{s}$ = 57 TeV

Arrival directions

- the degree of correlation with VCV catalog is stable (about 33%)
- definitive conclusions must await additional data

Photons and neutrinos

- flux photon limits above 1 EeV (top-down models disfavored)
- updated neutrino upper limits
- **observation/absence of cosmogenic neutrinos/photons relevant for the understanding of UHCR origin at the highest energies**

Future at AUGER

Goal: identify the primary cosmic ray nature at the highest energy
→ investigate the interaction properties more deeply

We have started moving towards and upgrade of the **surface detector**:

- front-end electronics going to faster sampling to better separate the electromagnetic and the muon components

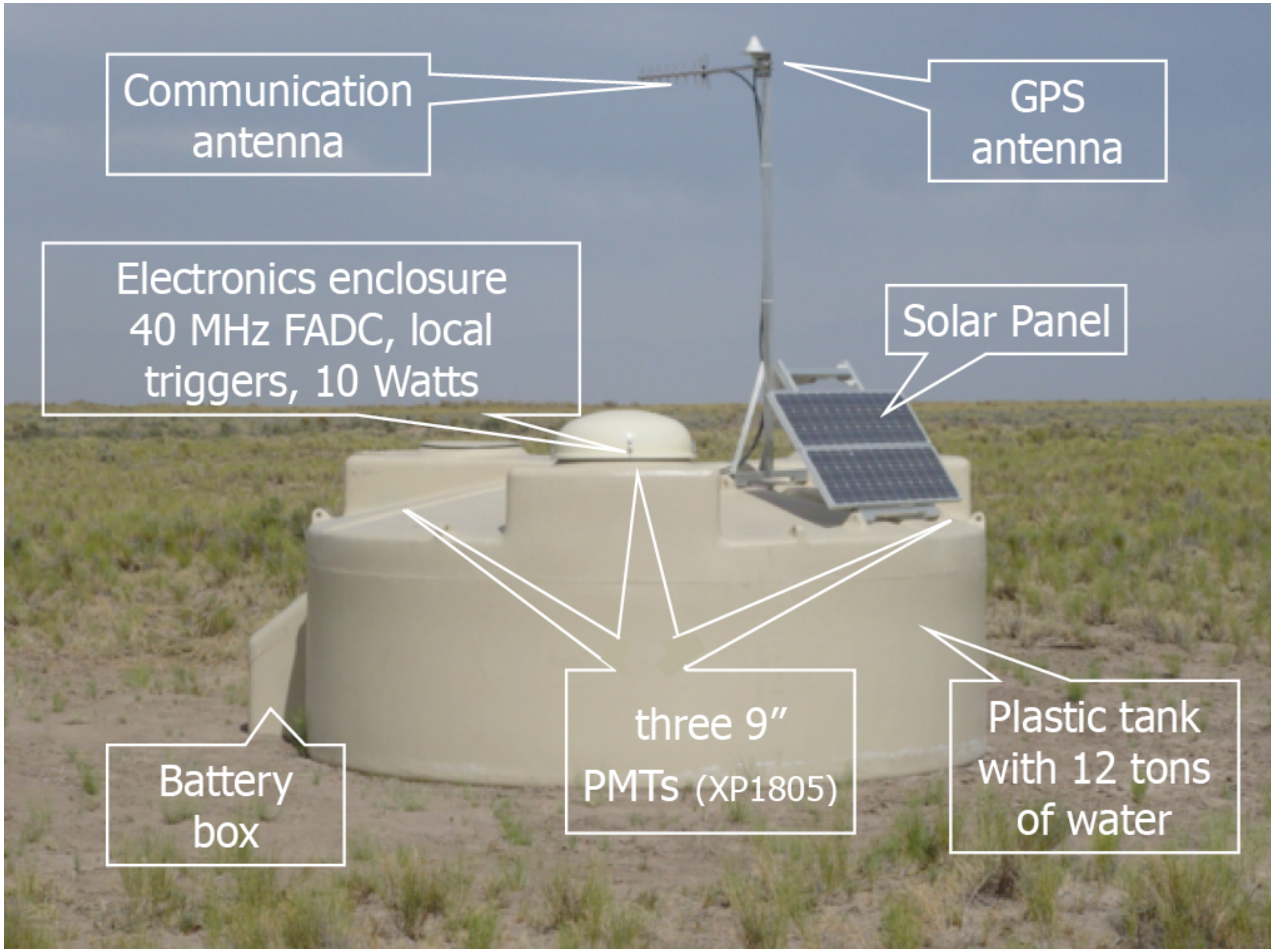
Work on the field and simulation campaigns started

Other techniques being investigated:
Use of RPCs
dense FD coverage
array of scintillators

BACK-UP slides

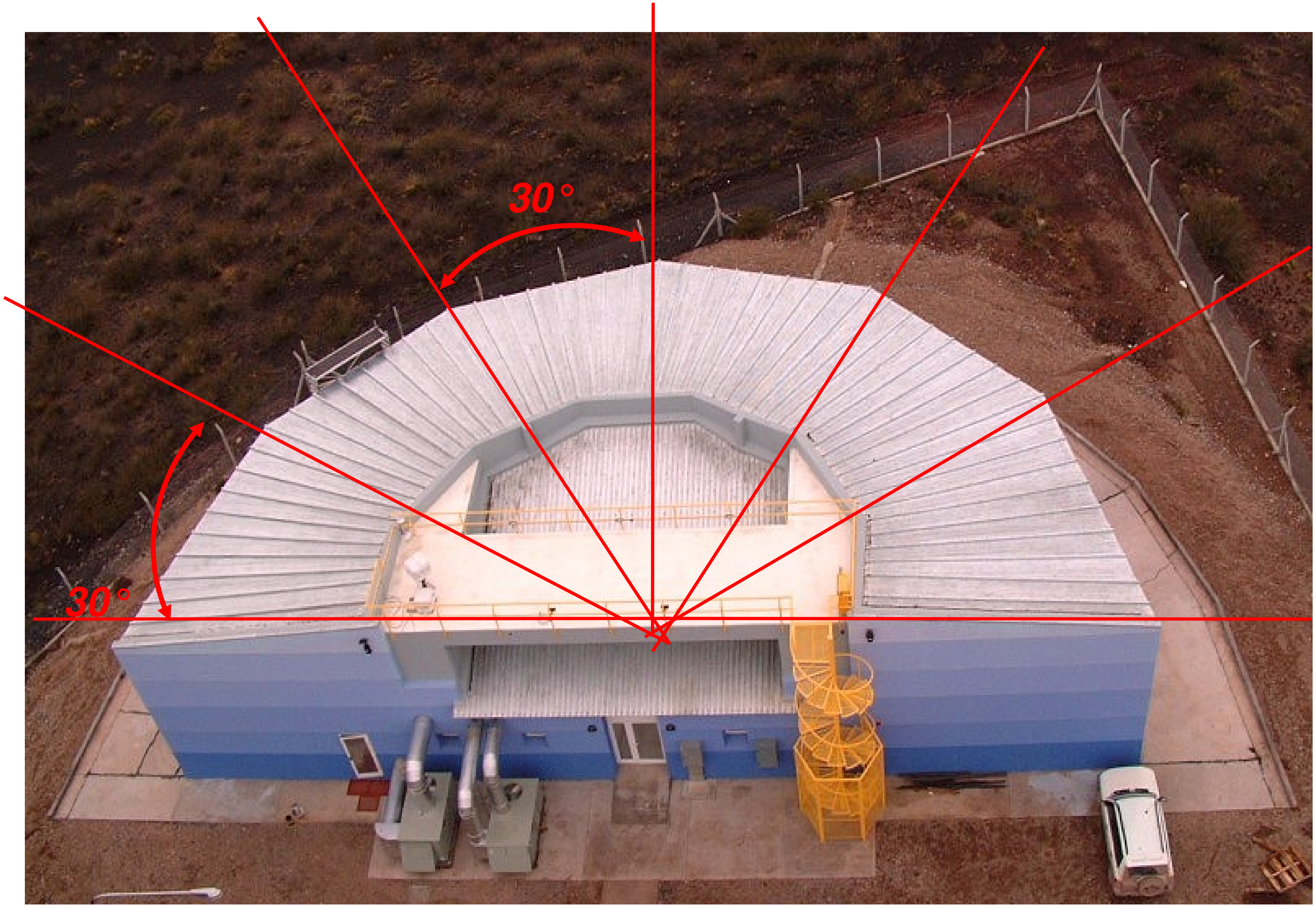
A station of the Surface Detector

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



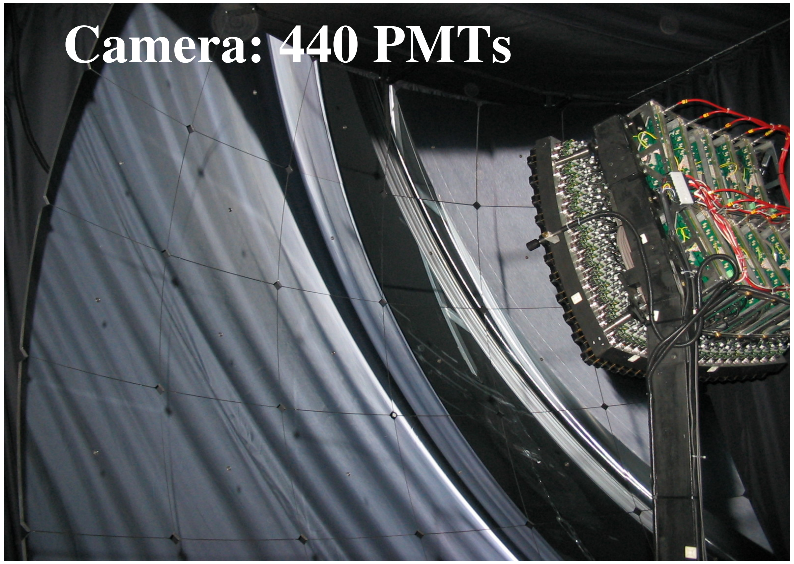
DAQ : 40 MHz FADC sampling (10 bit resolution)

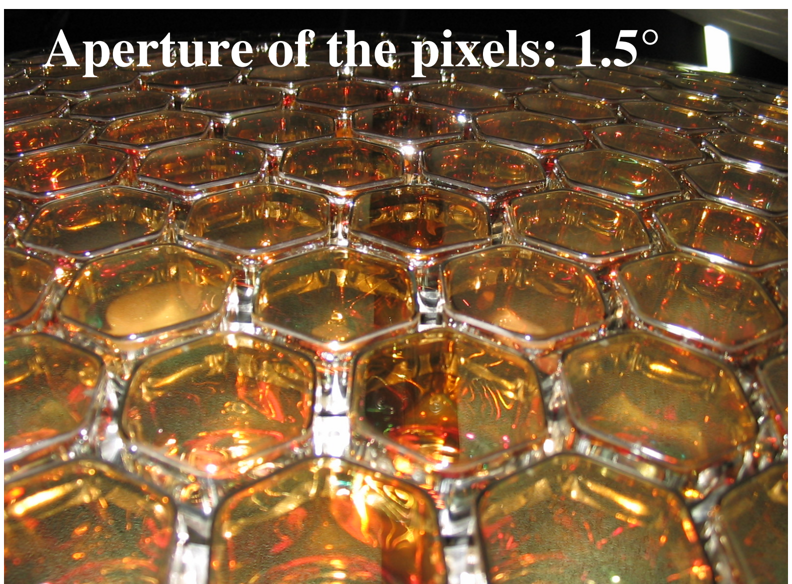
The fluorescence detector (FD)

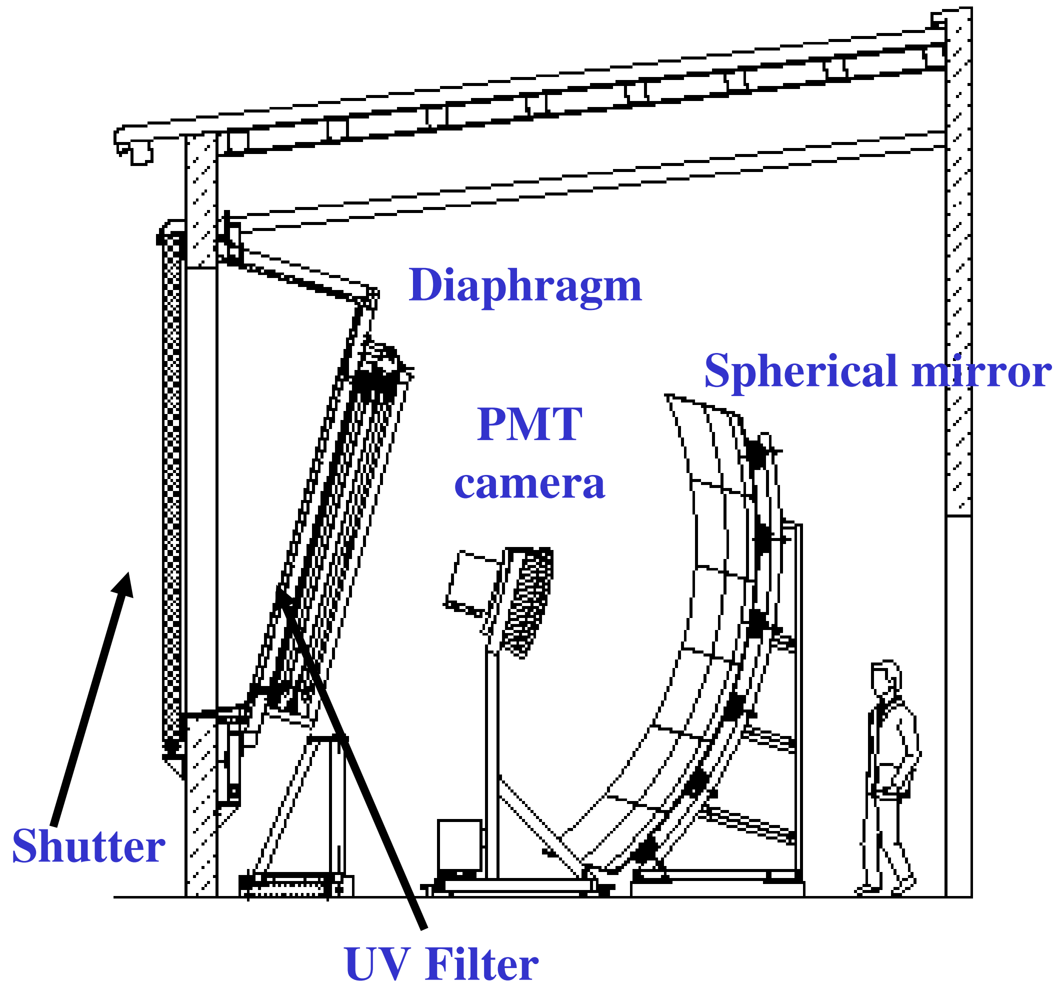


6 telescopes, each with 30° x 30° FOV

The fluorescence detector (FD)



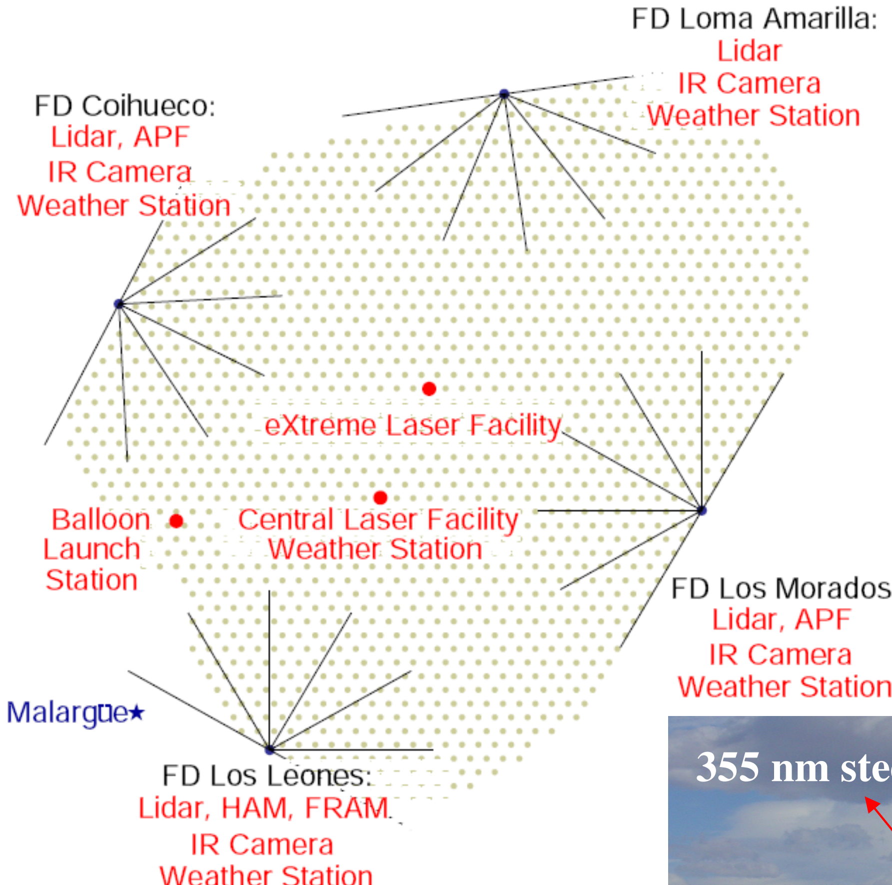




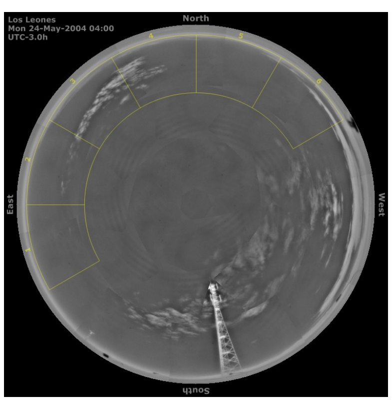
Atmospheric monitoring

balloons

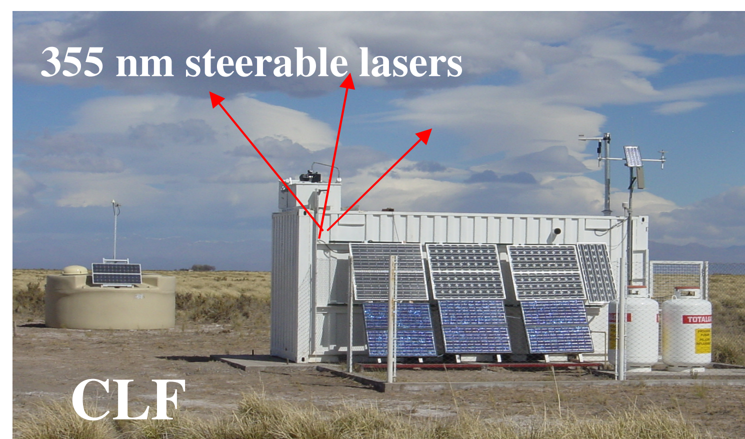
backscatter Lidar



IR cloud camera



Central Laser Facility

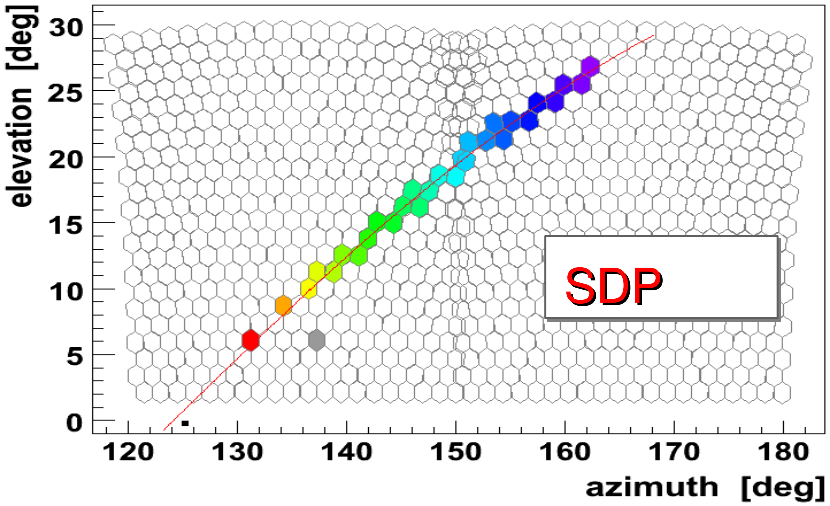


K. Louedec @ **ICRC 2011**

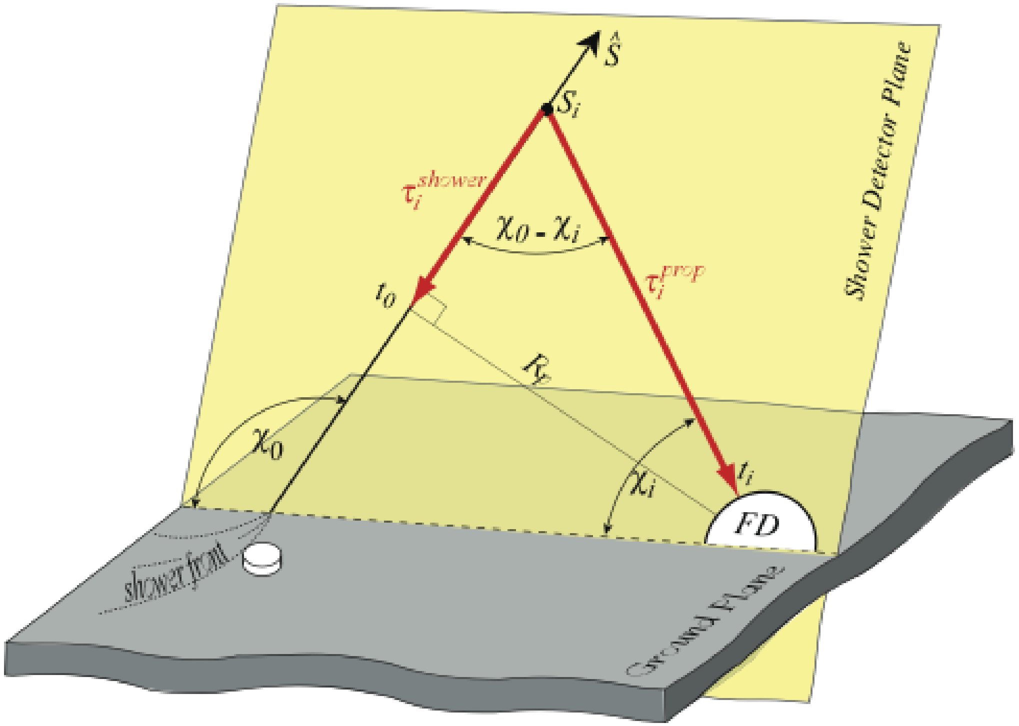
Observables and Detector Performance

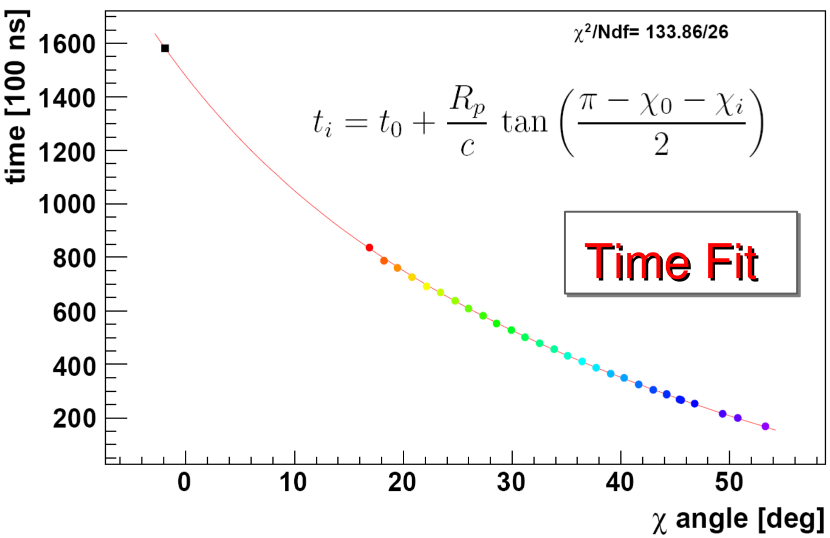
- Reconstruction of arrival directions with FD/SD/Hybrid
- Reconstruction of longitudinal profile
- Energy determination

FD-Hybrid geometry reconstruction



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

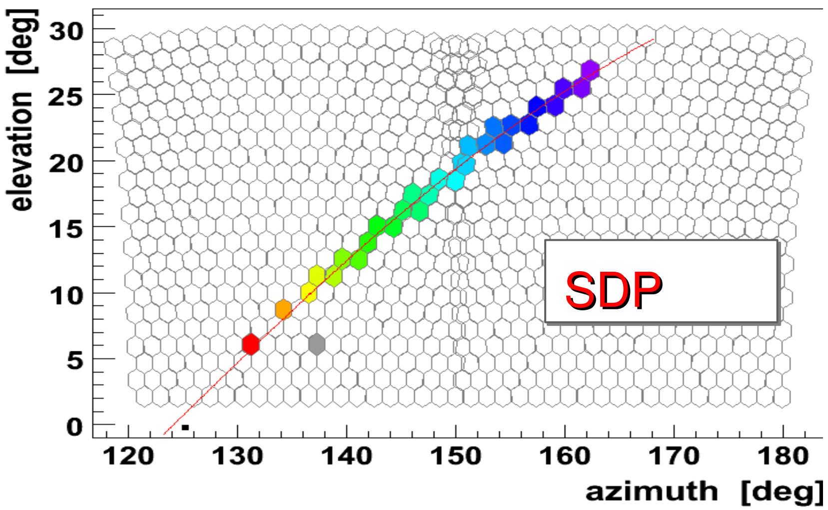




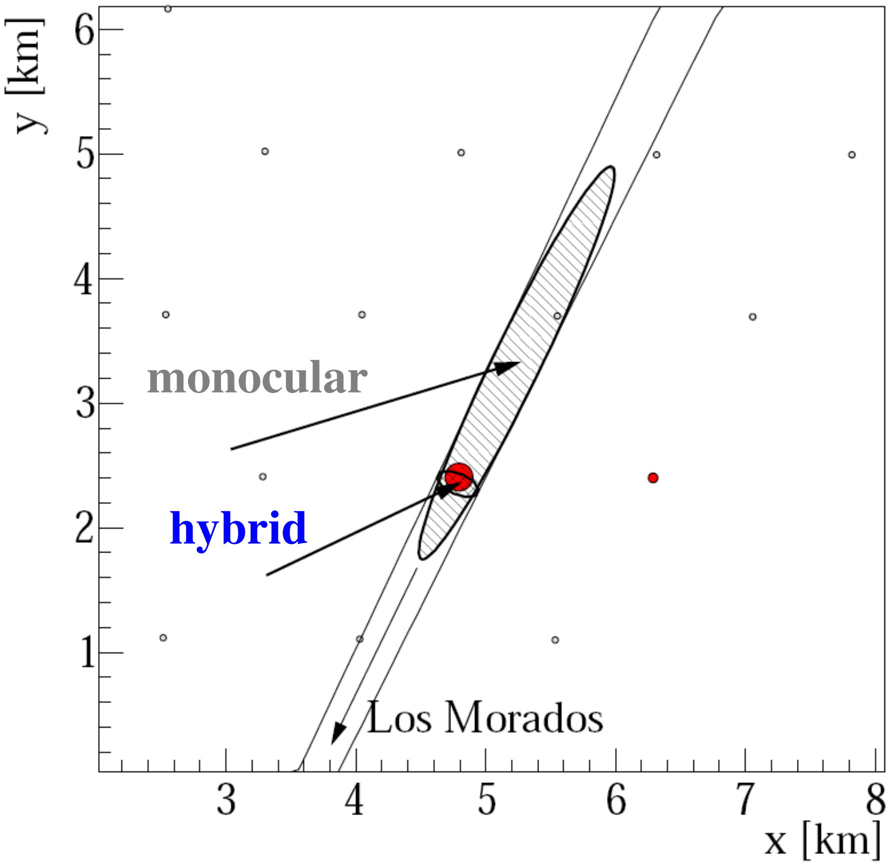
$$t_i = t_0 + \frac{R_p}{c} \tan\left(\frac{\pi - \chi_0 - \chi_i}{2}\right)$$

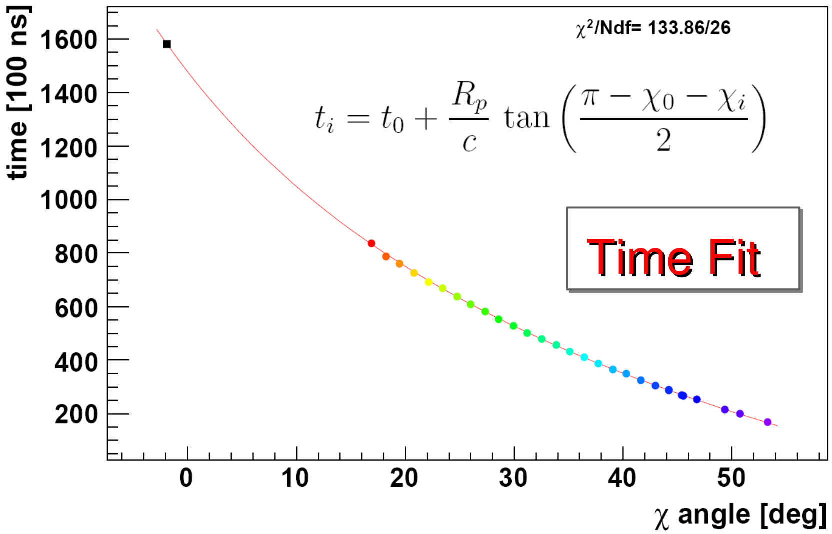
- Shower axis from the time-sequence of triggered FD pixels plus the information from the "hottest" SD station

FD-Hybrid geometry reconstruction



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



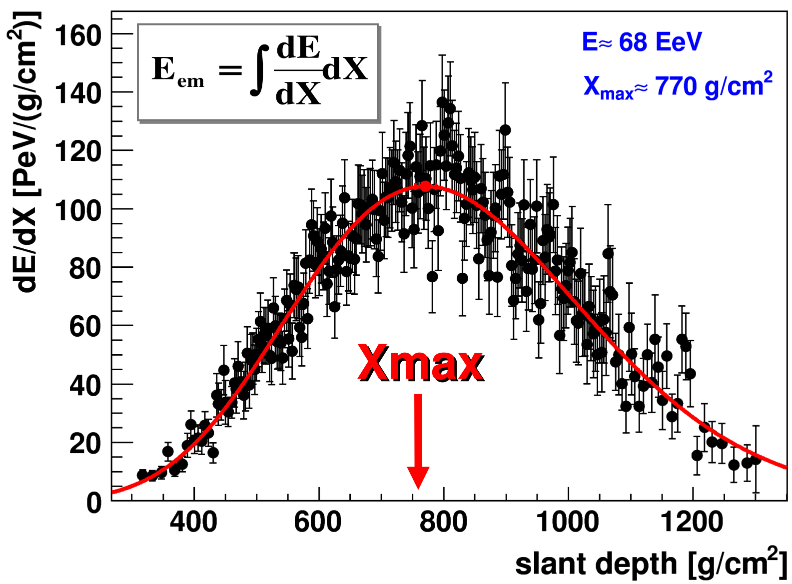


Hybrid angular resolution ~ 0.6°

Core resolution about 50 meters

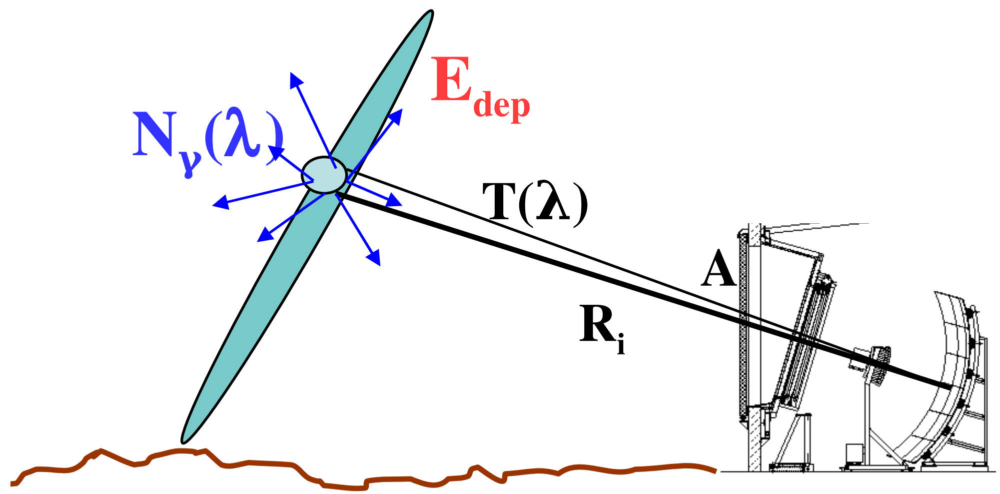
FD: energy determination

Longitudinal Profile



Energy "Calorimetric measurement"

Almost model independent



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

Fluorescence yield (from laboratory measurements)

Geometry

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

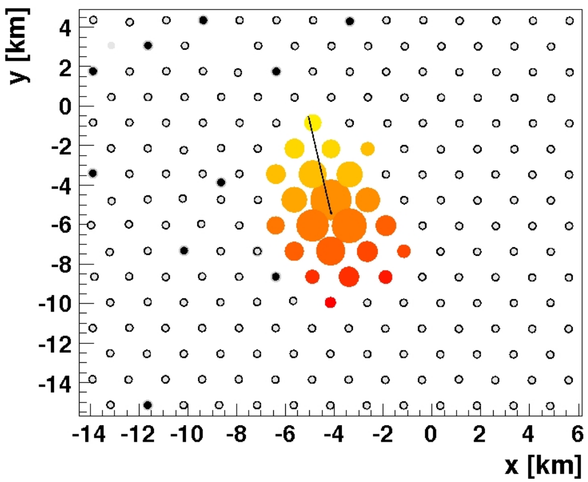
Atmosphere

$$T(\lambda)$$

Detector calibration

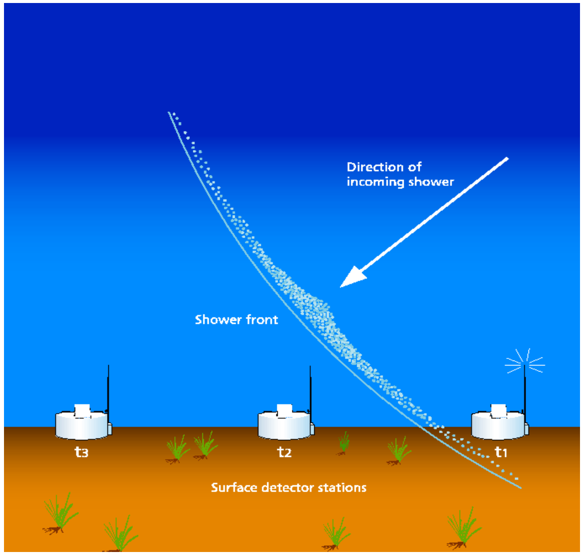
SD reconstruction

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

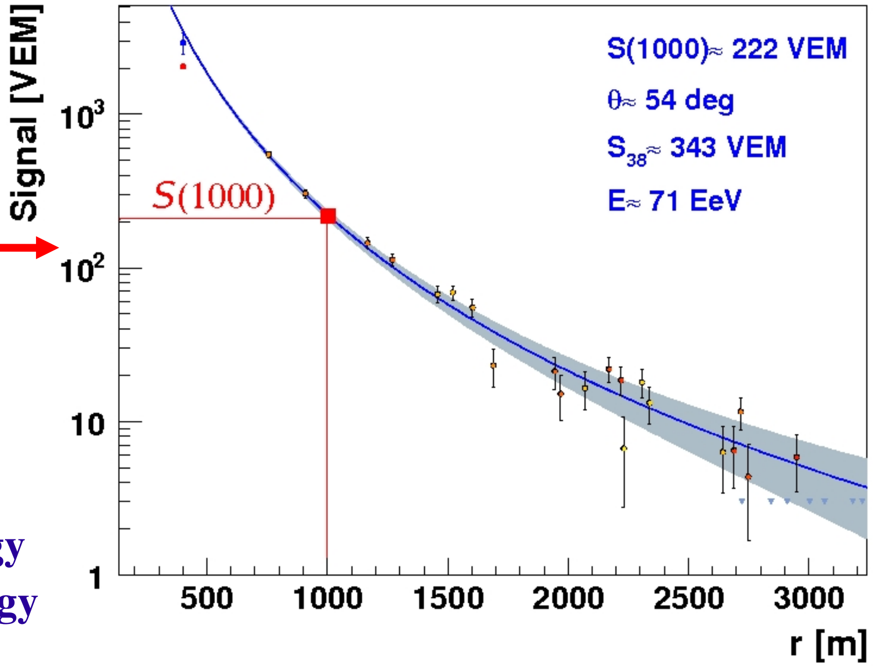


Angular resolution

E > 10^{18} eV, ~ 3 stations, < 2°
E > 10^{19} eV, ~ 6 stations, < 1°



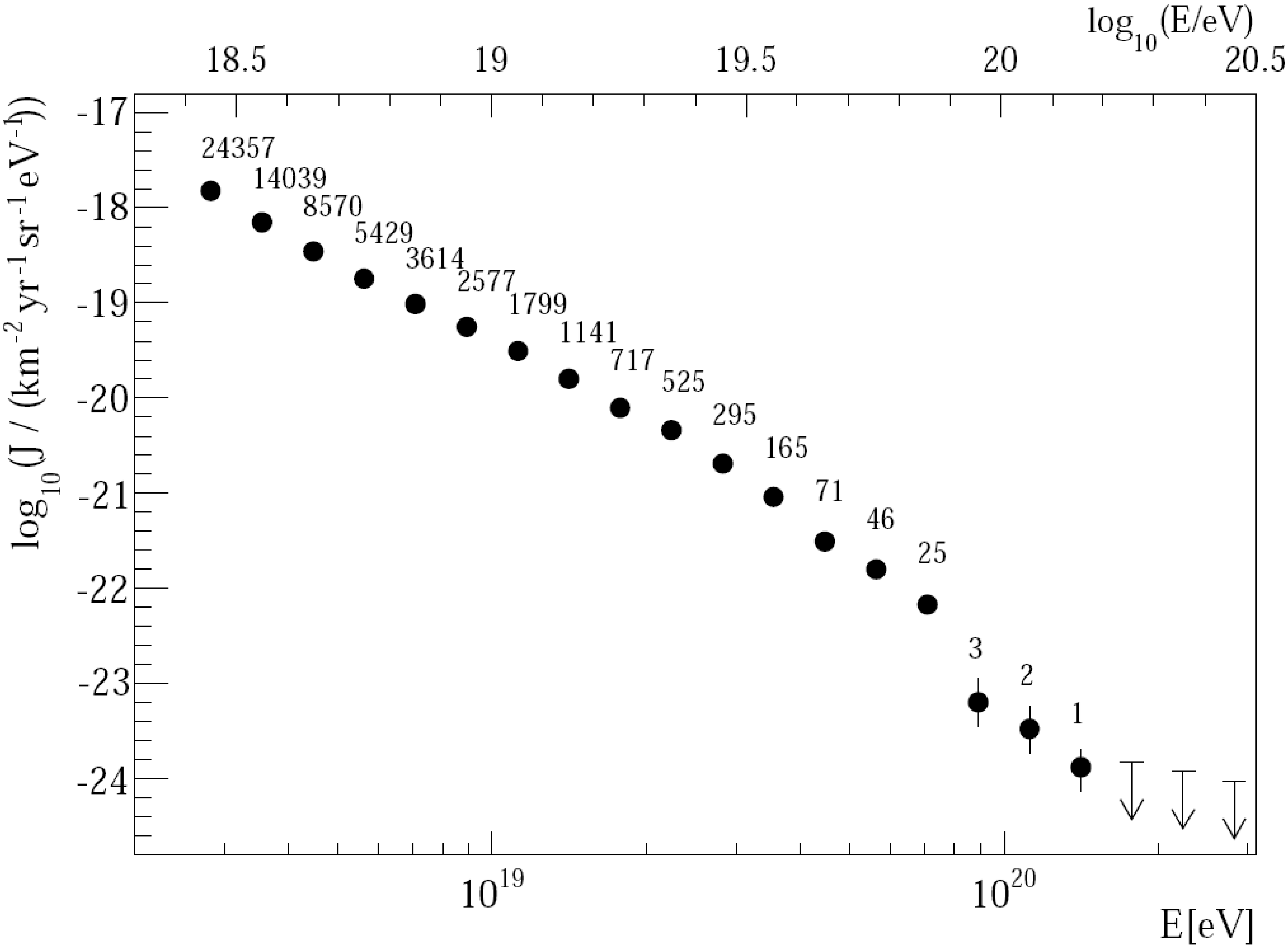
Energy estimator: **S(1000)**
particle density at 1000 m from shower axis



Systematic uncertainties on energy determination

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

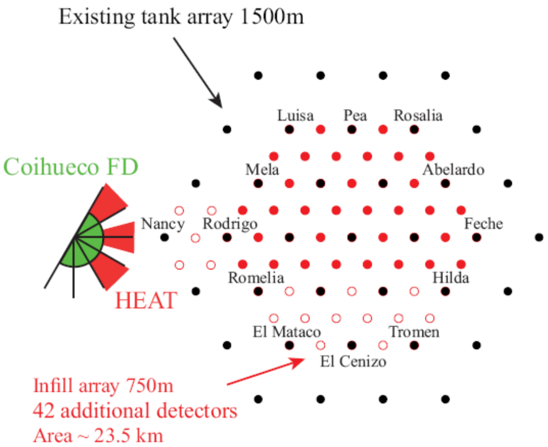
SD spectrum

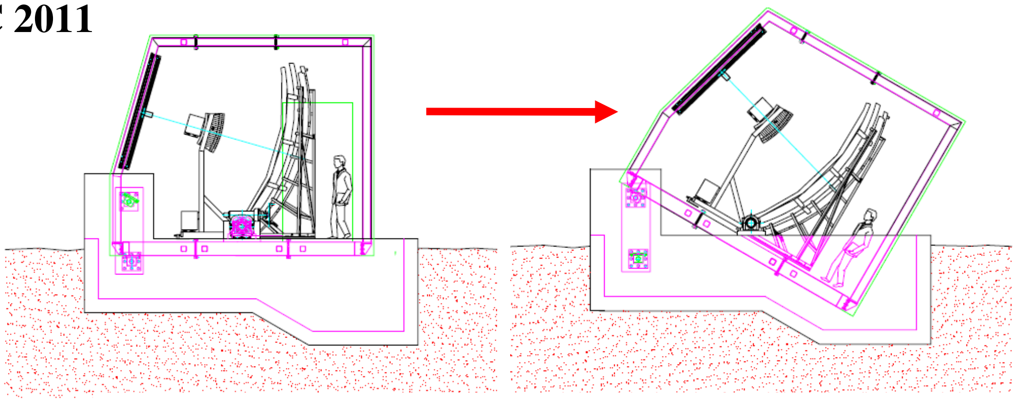


log10(E/eV)
18.5
19
19.5
20
20.5
log10(J / (km-2 yr-1 sr-1 eV-1))
-17
-18
-19
-20
-21
-22
-23
-24
24357
14039
8570
5429
3614
2577
1799
1141
717
525
295
165
71
46
25
3
2
1
10^19
10^20
E[eV]

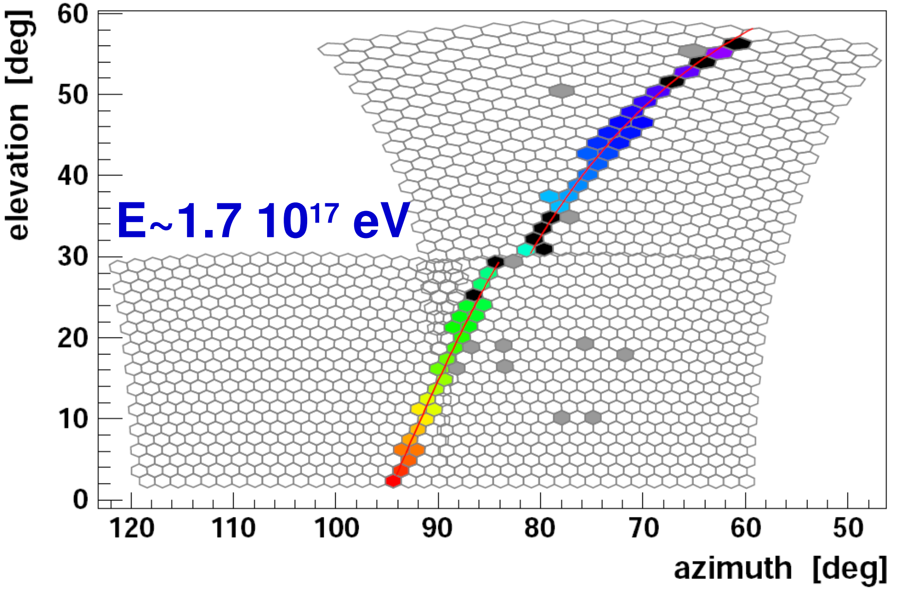
FD Auger enhancement: HEAT

H-J Mathes @ **ICRC 2011**





3 telescopes nearby Coihueco
30° up to 60° elevation

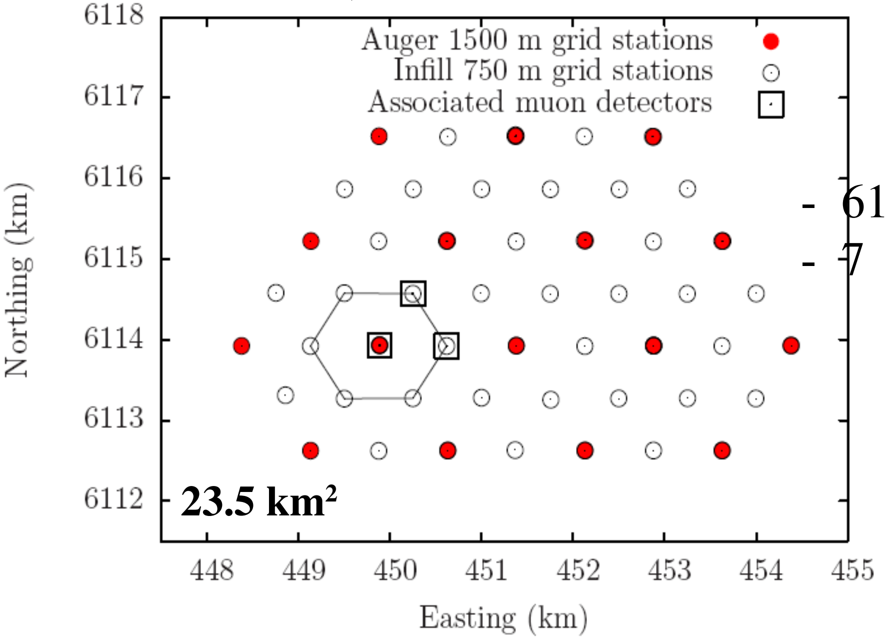


Higher elevation
lower energies (~ 10^{17} eV) unbiased observation of longitudinal profile

Taking data since Sept. 2009

SD Auger enhancement: AMIGA

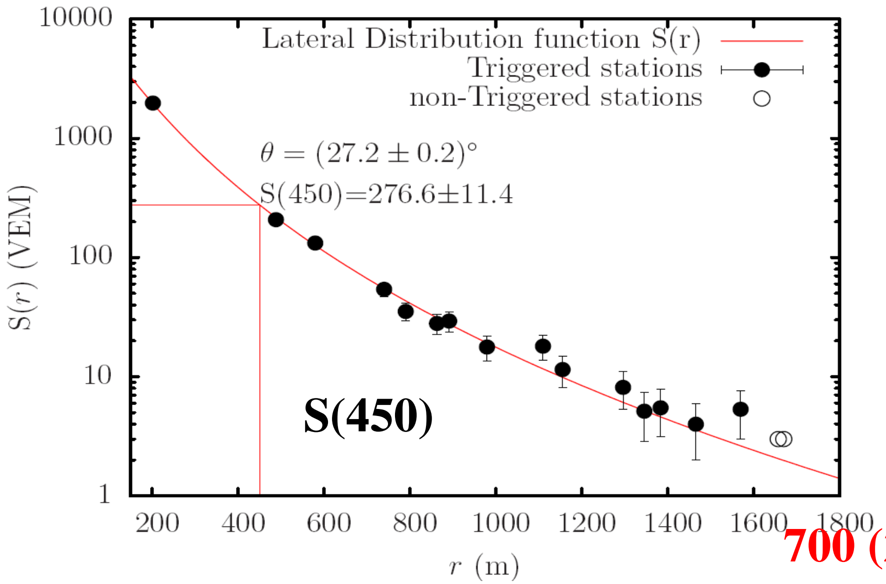
I.Maris, F. Sanchez @ **ICRC 2011**

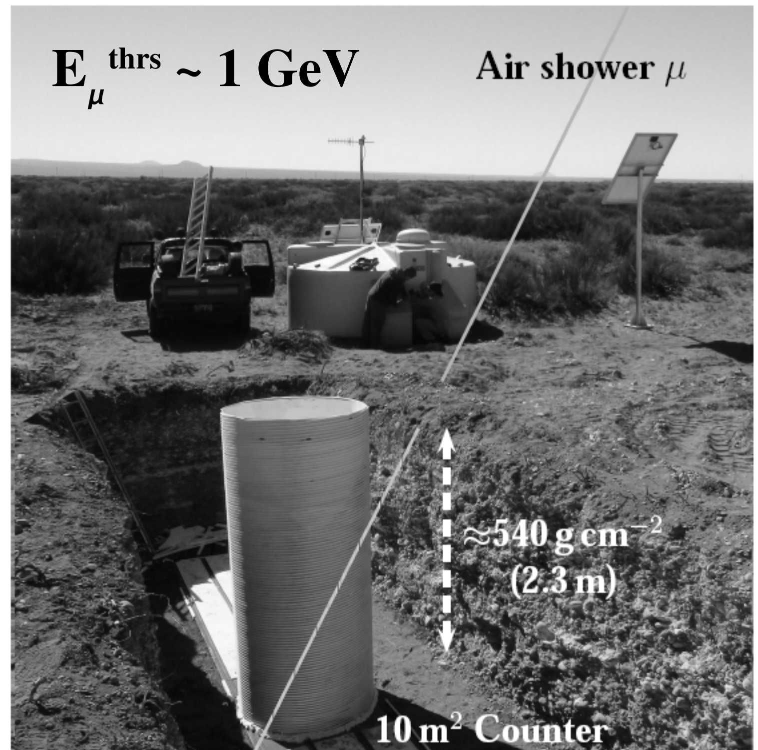


INFILL array (Cherenkov stations) and Muon detectors (scintillators)

- 61 stations with spacing 750 m
- 7 buried scintillator modules installed

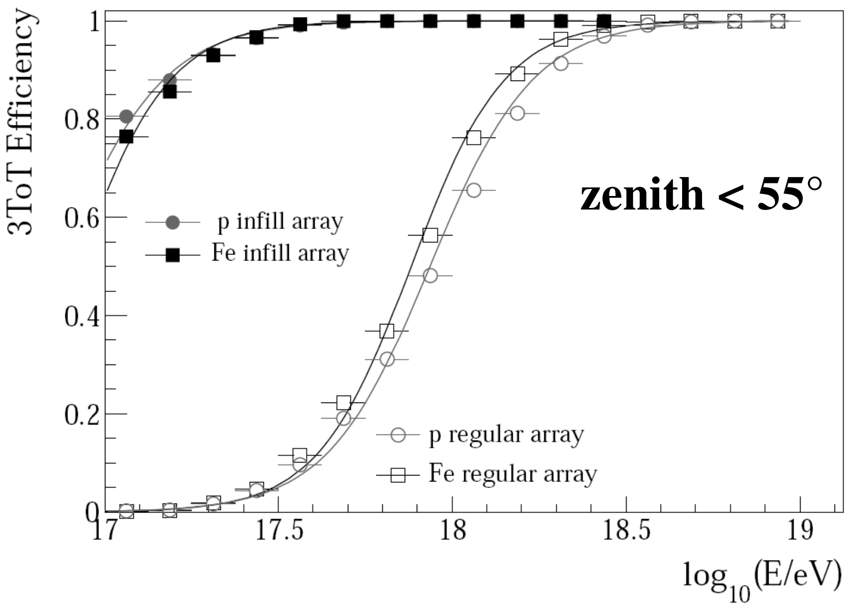
Exposure: (26.4 ± 1.3) km² sr yr





700 (20, 4) events/ month E > $10^{17.5\ (18,\ 18.5)}$ eV

Infill array preliminary results



Full Efficiency above 3 10^{17} eV

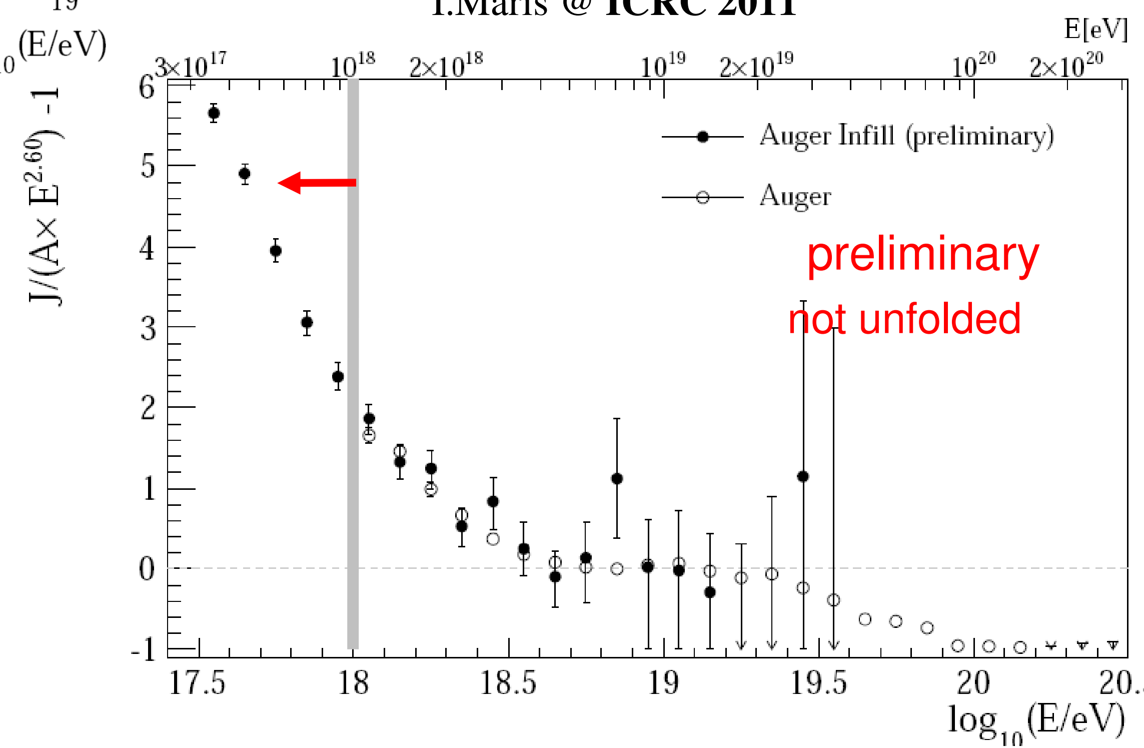
Angular resolution

1.3° for at least four stations

1° for at least six stations

I.Maris @ **ICRC 2011**

Spectrum Extended down to 0.3 EeV



systematic uncertainties due to SD resolution not yet included

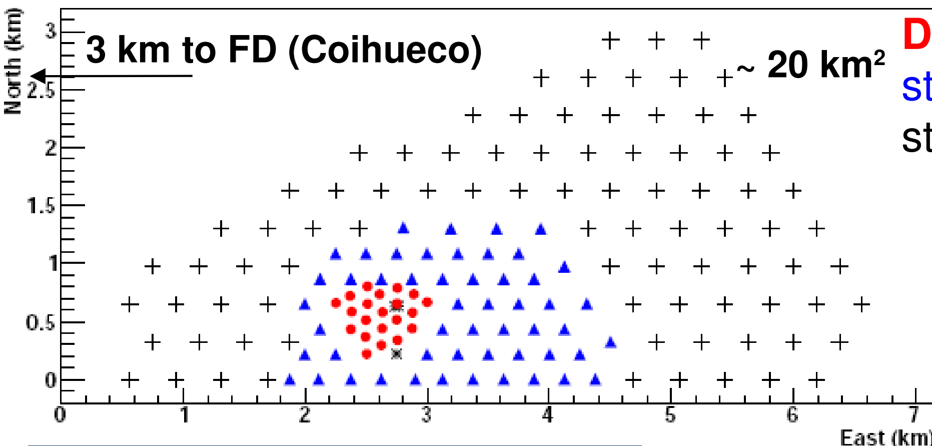
AERA: Radio detection

B. Revenu, J.L Kelley @ **ICRC 2011**

Observation of radio emission from electromagnetic cascade

- geomagnetic field
- charge separation

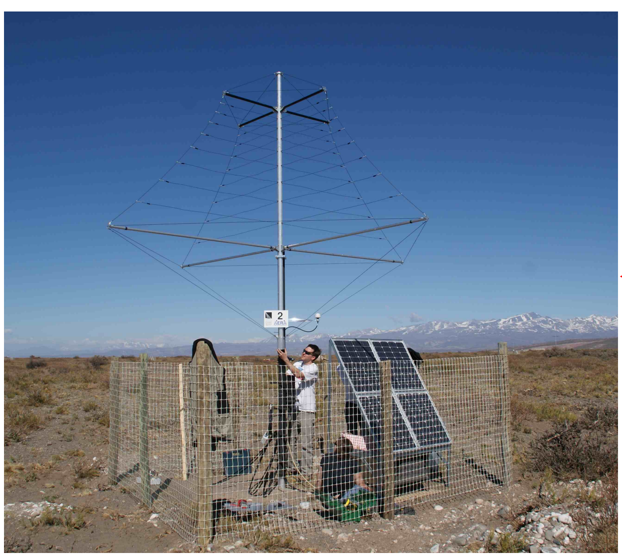
VHF band 10-100 MHz



Deployed in 2010 (21 Radio stations, 150m)
stage 2 (250 m)
stage 3 (350 m)

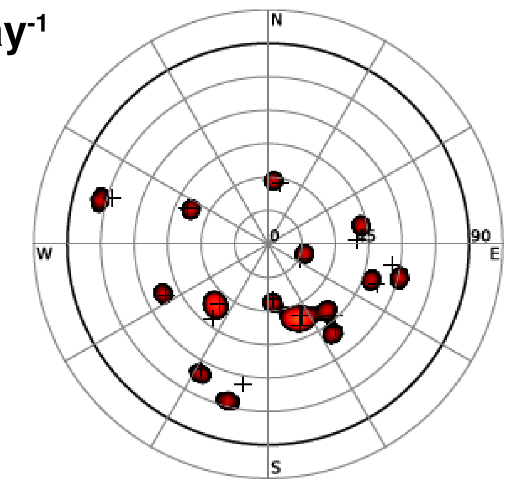
First physical radio-hybrid events

Radio/SD 0.5 day^{-1}



$E_{thres} \sim 10^{17}$ eV

Logarithmic periodic dipole antenna (two polarizations)



Polar plot, SD and radio reconstruction

First Radio/FD/SD super hybrid event observed

Microwave detection

Observation of microwave emission from electromagnetic cascade

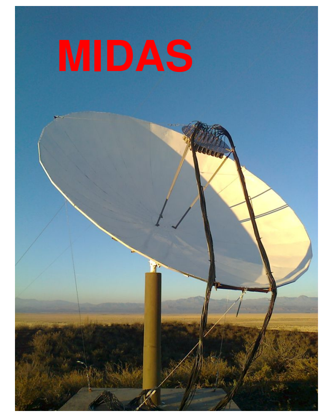
Hypothesis: Molecular Bremsstrahlung isotropic emission — **P. Gorham et al., Phys. Rev. D, 2008, 78**

~100% duty cycle – negligible atmospheric absorption

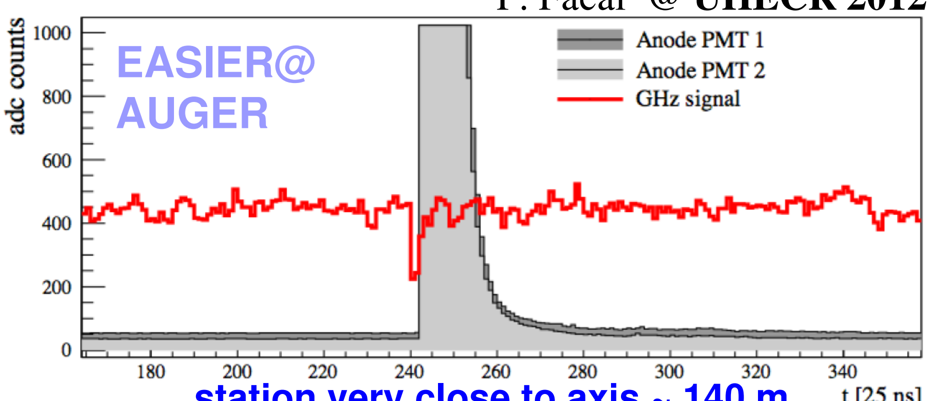
Several prototypes being developed, many operating (or planned to be) at the Auger Site

array of antennas

parabolic dish



P. Facal @ **UHECR 2012**



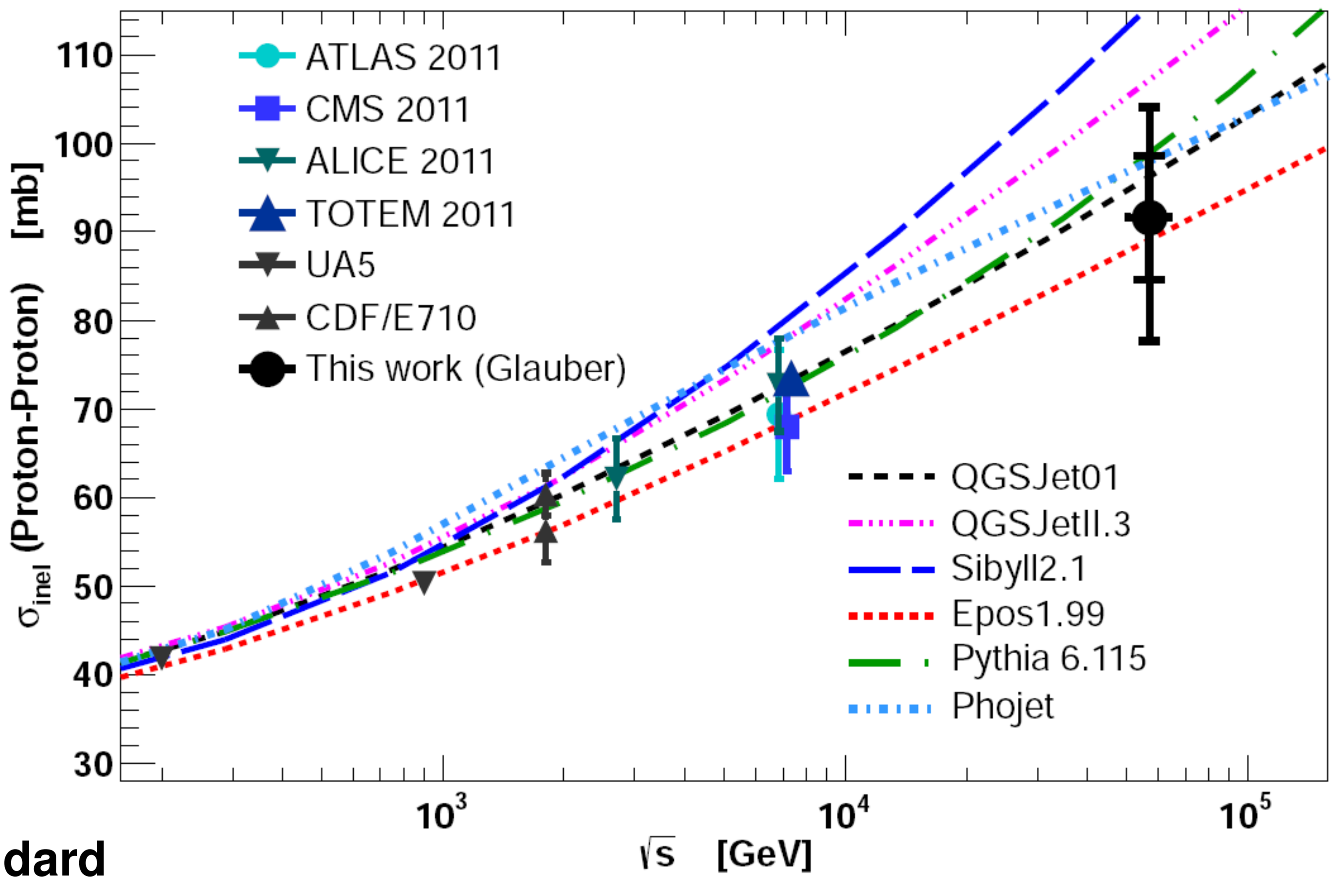
station very close to axis ~ 140 m

Energy from SD =14 EeV **Zenith= 30°**

First evidence of GHz emission from EAS
- compatible with MBR (linear scaling)
- thought other processes not excluded (coherent effects)

p-p inelastic cross-section

The Pierre Auger Collaboration, Phys. Rev. Lett. 109, 062002 (2012)



Using standard Glauber formalism

$$\sigma_{pp}^{\rm inel} = \left[92 \ \pm 7({\rm stat}) \ ^{+9}_{-11}({\rm sys}) \ \pm 7({\rm Glauber})\right] \ {\rm mb}$$

$$\sigma_{pp}^{\rm tot} = \left[133 \ \pm 13({\rm stat}) \ ^{+17}_{-20}({\rm sys}) \ \pm 16({\rm Glauber})\right] \ {\rm mb}$$

Future at AUGER

Goal: identify the primary cosmic ray nature at the highest energy
→ investigate the interaction properties more deeply

We have started moving towards and upgrade of the **surface detector**:

- front-end electronics going to faster sampling (**100 MHz or more**)

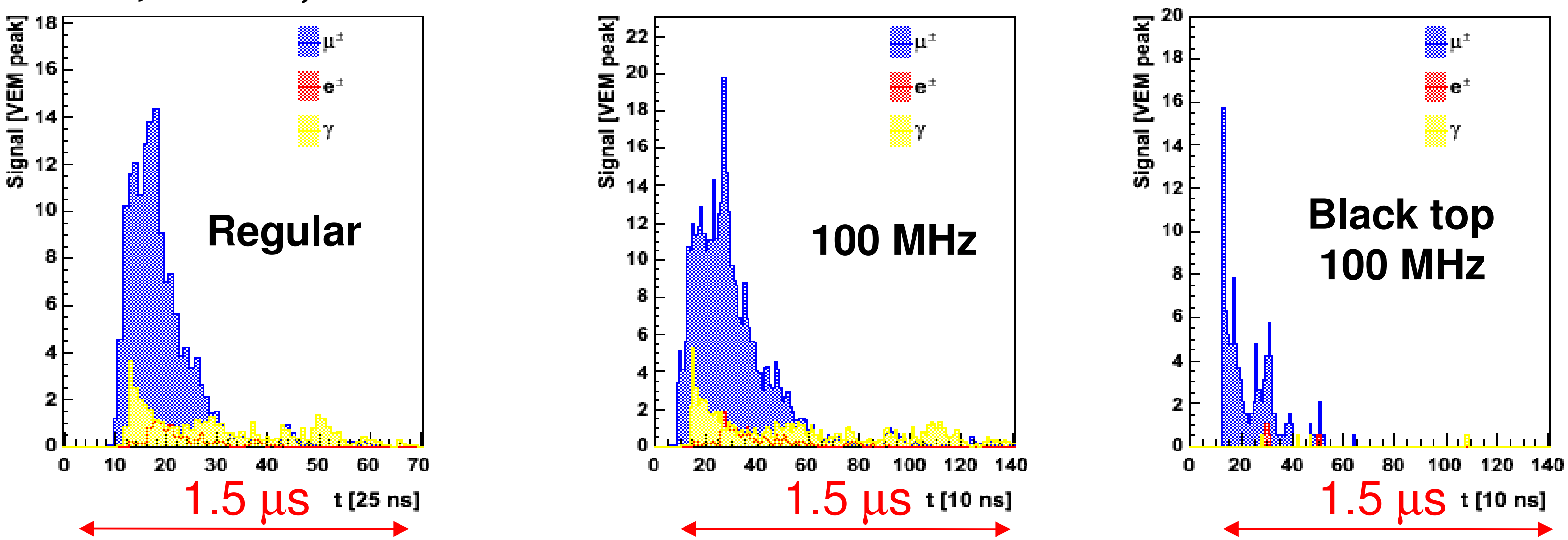
- changed station liners to have faster time response and better separate the electromagnetic and the muon components (**black top or similar options**)

Work on the field and simulation campaigns started

Other techniques being investigated:
Use of RPCs
dense FD coverage
array of scintillators

....work in progress

56°, 26 EeV, 900 m from axis



45°, 12 EeV, 900 m from axis