ECRS 2010
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General Overview of Recent Results from the Pierre Auger Observatory

Rossella Caruso
On behalf of the Pierre Auger Collaboration

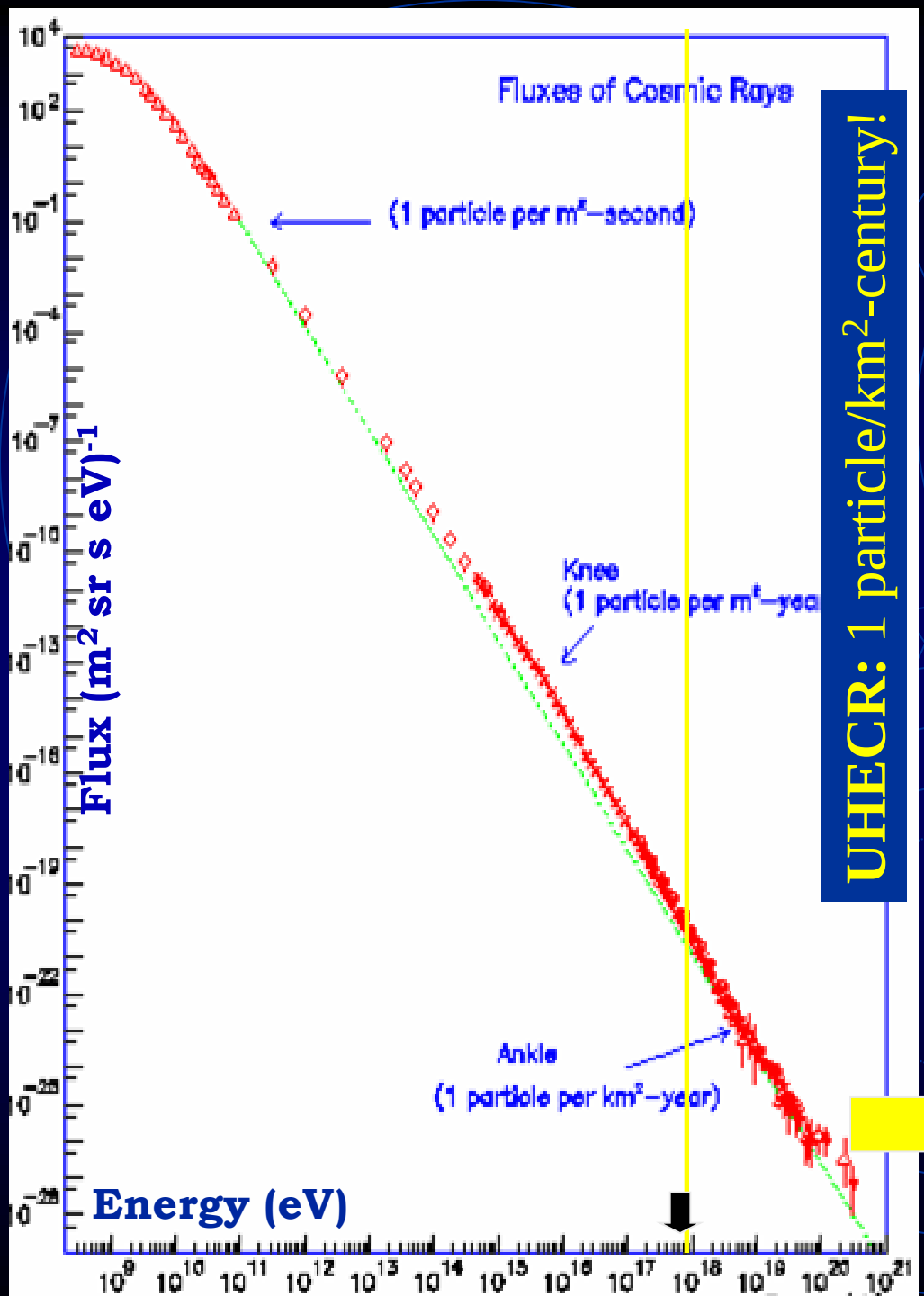
Department of Physics and Astronomy & INFN
University of Catania
Catania - Italy

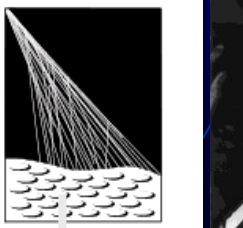
Experimental evidencies

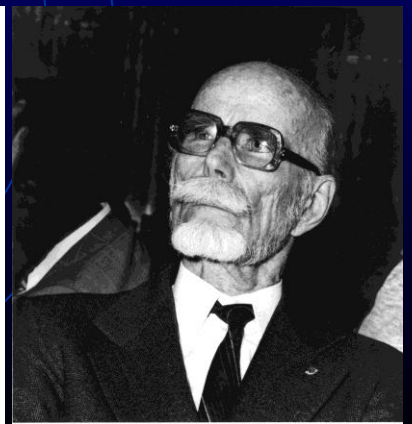
- 1938: Pierre Auger measured EAS;
- 1962: John Linsley detected first cosmic ray with $E>10^{20}$ eV (Volcano Ranch).
- Over the last 50 years detected few tenths events with $E>10^{20}$ eV by:

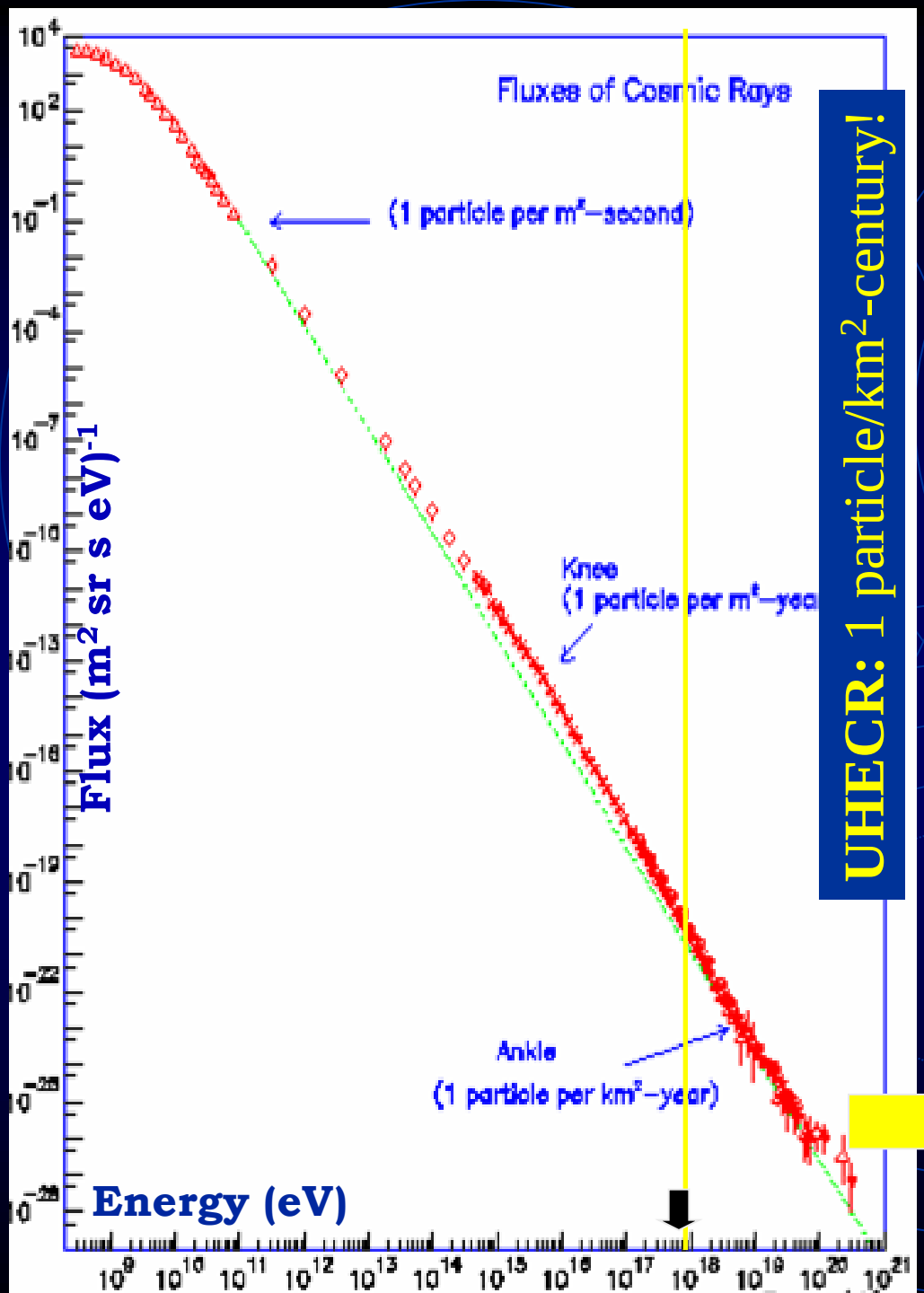
Volcano Ranch: (New Mexico,USA-1962)
Haverah Park: (UK, 1970)
Yakutsk: (Siberia, 1989)
Fly's Eye: (Utah -USA,1991)
AGASA: (Japan, 1993).
HIRES: (Utah -USA, 1997)

- 1991: Fly's Eye (fluorescence technique) measures first longitudinal profiles and the highest-energy event: $E=3.2 \times 10^{20}$ eV;
- Since 2004: Pierre Auger Observatory (first experiment with hybrid technique)









UHECR: 1 particle/km^2-century!

Present (still!) physics issues:

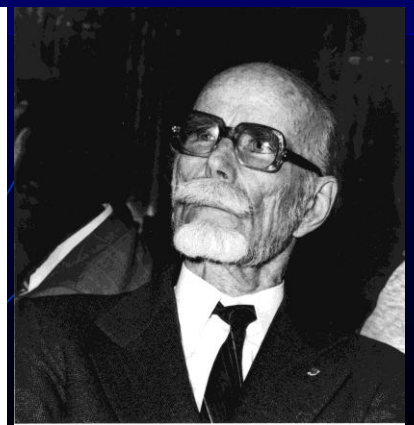
- Is there an end to the cosmic ray spectrum (GZK cutoff) ?
  Are the sources local (<100 Mpc)?

- Where do UHECRs come from?
  Anisotropy and sources.

- What is the primary nature of UHECR particles?
  Nuclei? Protons ?
  Gamma rays? Neutrinos? Or...?

- Do we understand air shower physics at ultra high energies?

PIERRE AUGER OBSERVATORY



The Pierre Auger experiment

- Milestones:

1992: proposed by J.Cronin & A.Watson,
2004: start of installation and data taking,
2008: completion of the Southern Observatory

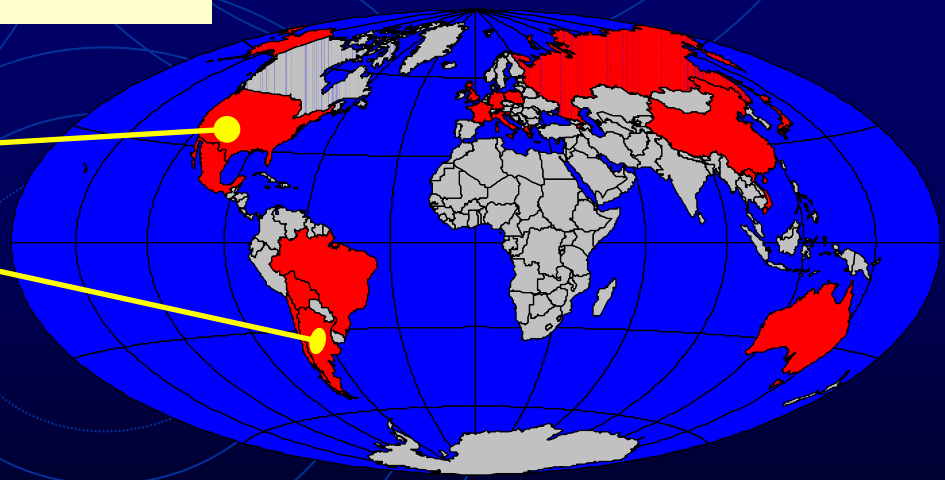
- International Collaboration

> 280 researchers from over 70 istitutions and 17 countries:
Argentina, Australia, Bolivia, Brazil, Czech Republic, France, Germany, Italy, Mexico, Netherlands, Poland, Portugal, Slovenia, Spain, U.K., U.SA., Vietnam

PIERRE AUGER OBSERVATORY

- Total sky coverage:

Northern-hemisphere→ USA
Southern-hemisphere→ Argentina

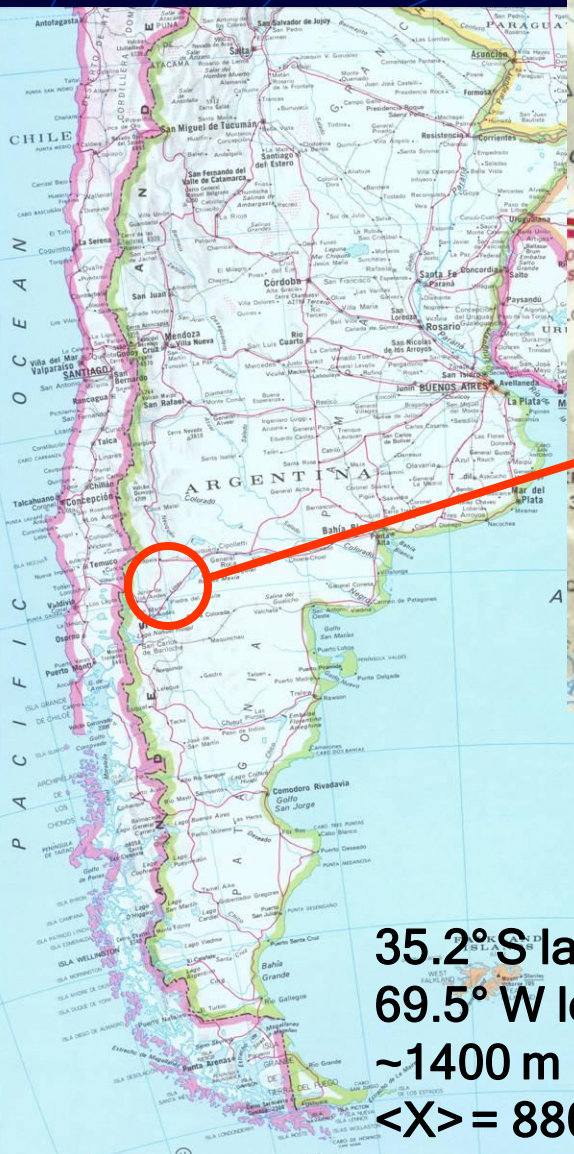


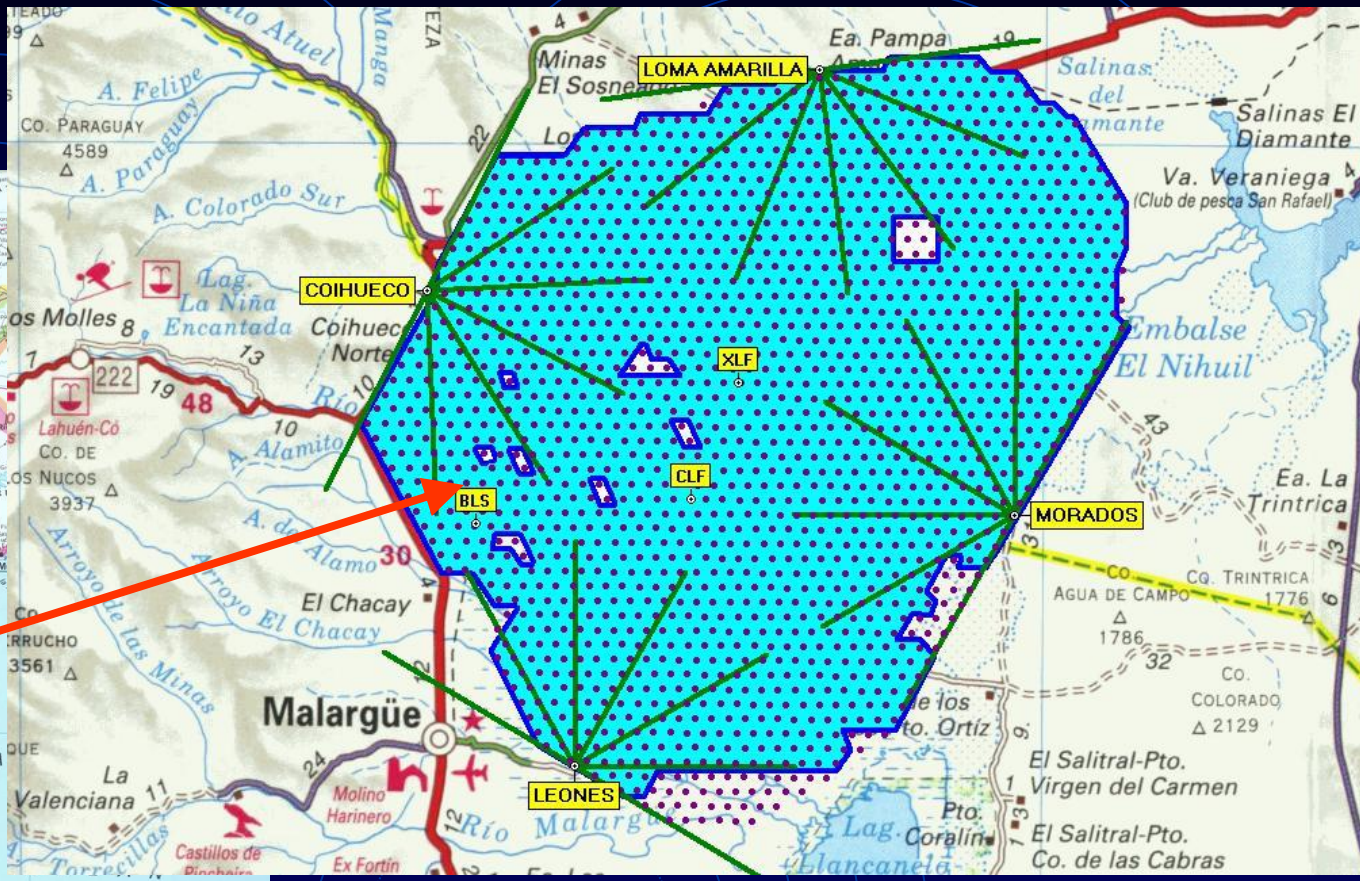
- Hybrid detector technique

- Very high performances:

High statistics, long duration
Data taking during installation
Good geometrical and energetic resolution

Pierre Auger Southern Observatory



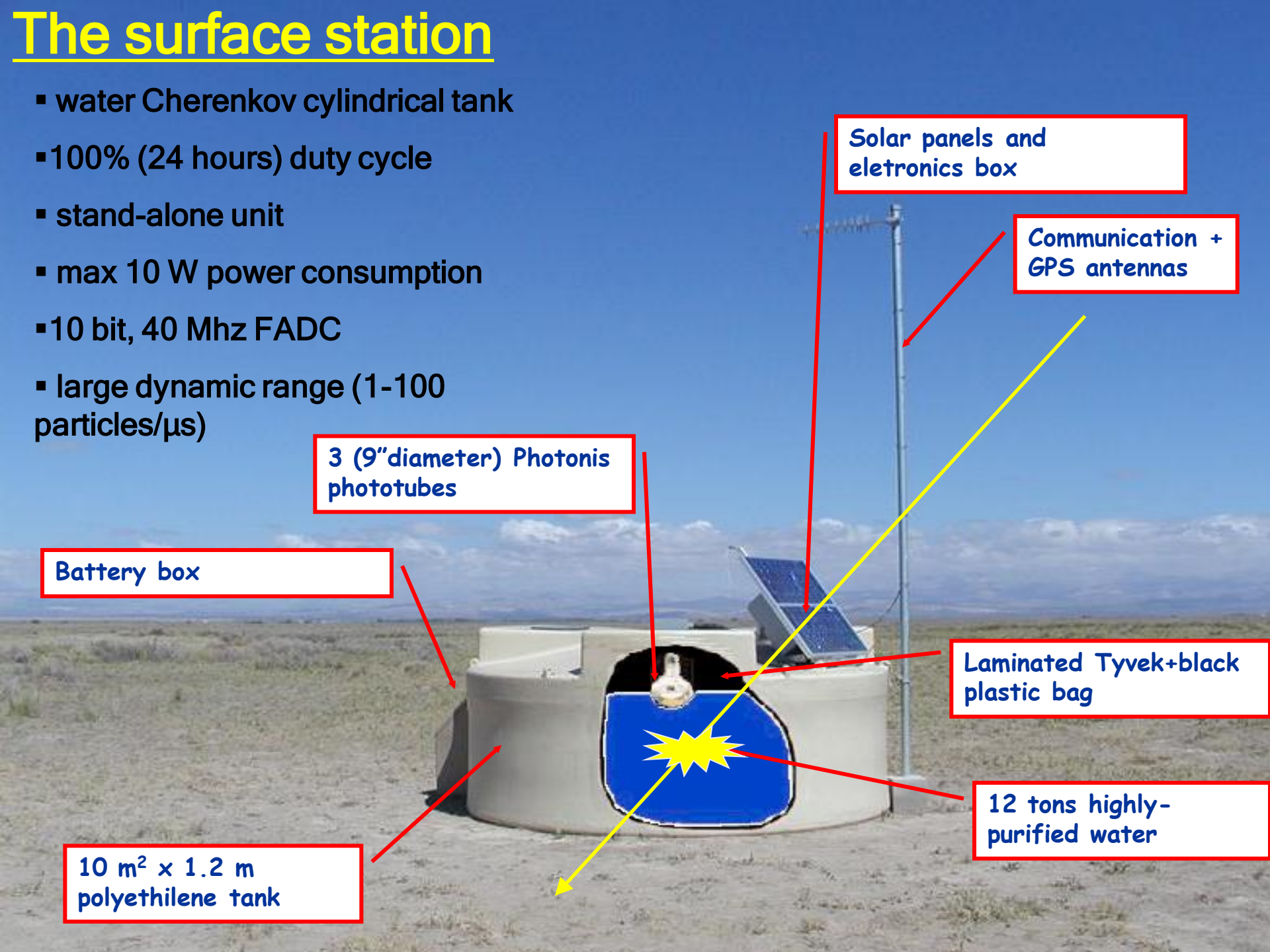


35.2° S latitude
69.5° W longitude
~1400 m a.s.l.
$\langle X \rangle = 880$ g/cm^2

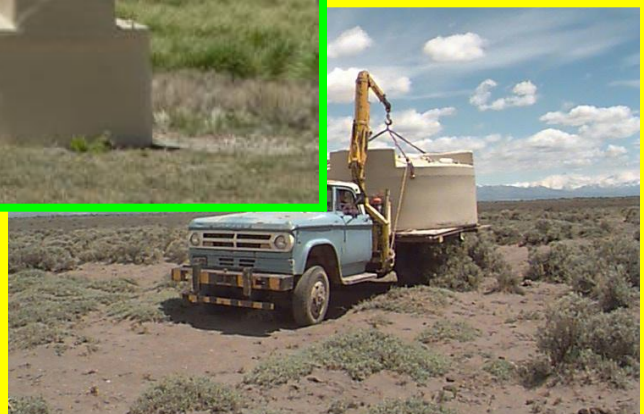
- Area $\simeq$ 3000 km^2, Aperture $\simeq$7000 km^{2}sr
- 24 peripheral fluorescence telescopes (FD)
- 1600 water Cherenkov stations (SD)

The surface station

- water Cherenkov cylindrical tank
- 100% (24 hours) duty cycle
- stand-alone unit
- max 10 W power consumption
- 10 bit, 40 Mhz FADC
- large dynamic range (1-100 particles/μs)




ESSO

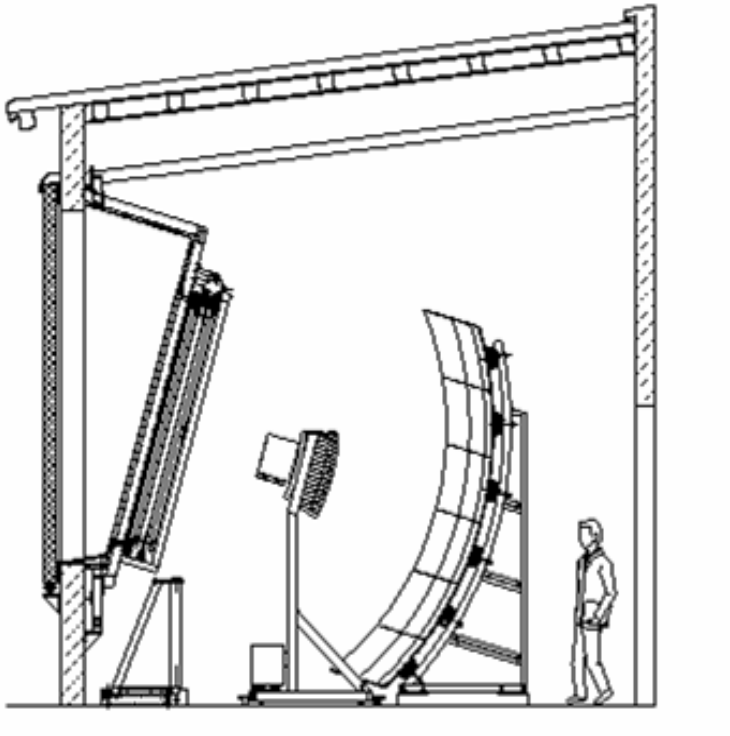


The Fuorescence telescope

Mirror

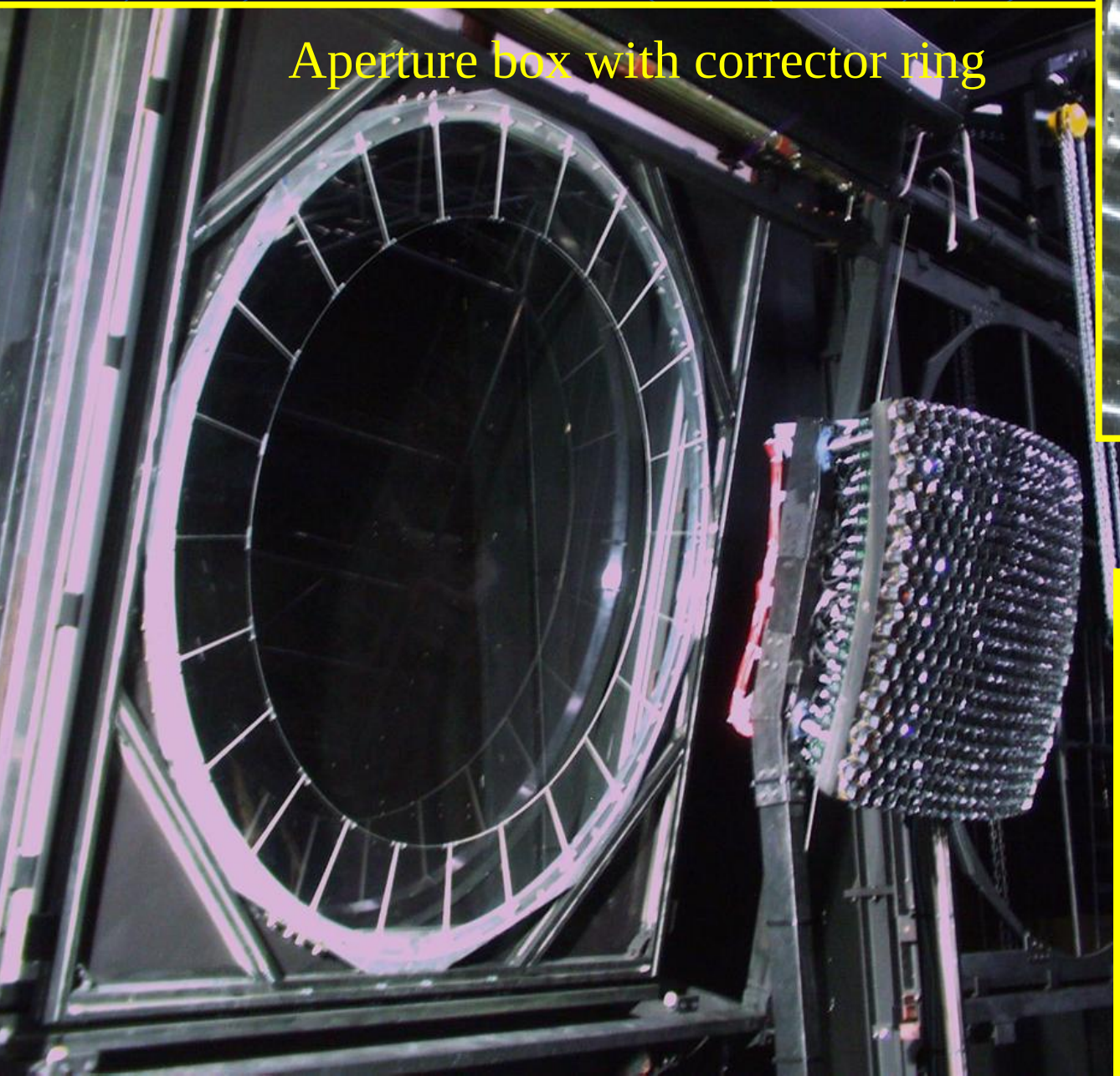
PMT
Camera

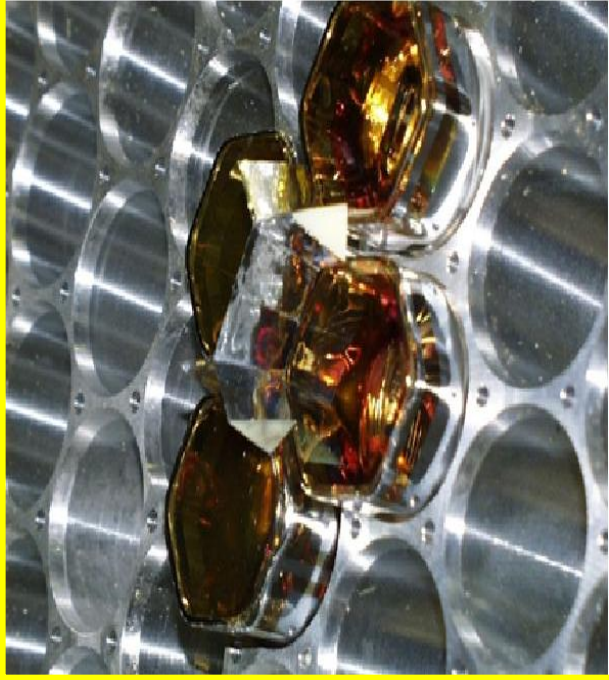
Front-end
electronics

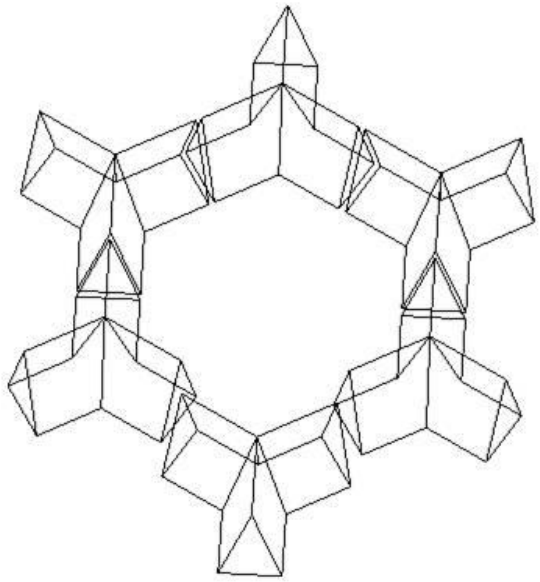


The Fuorescence telescope

Aperture box with corrector ring

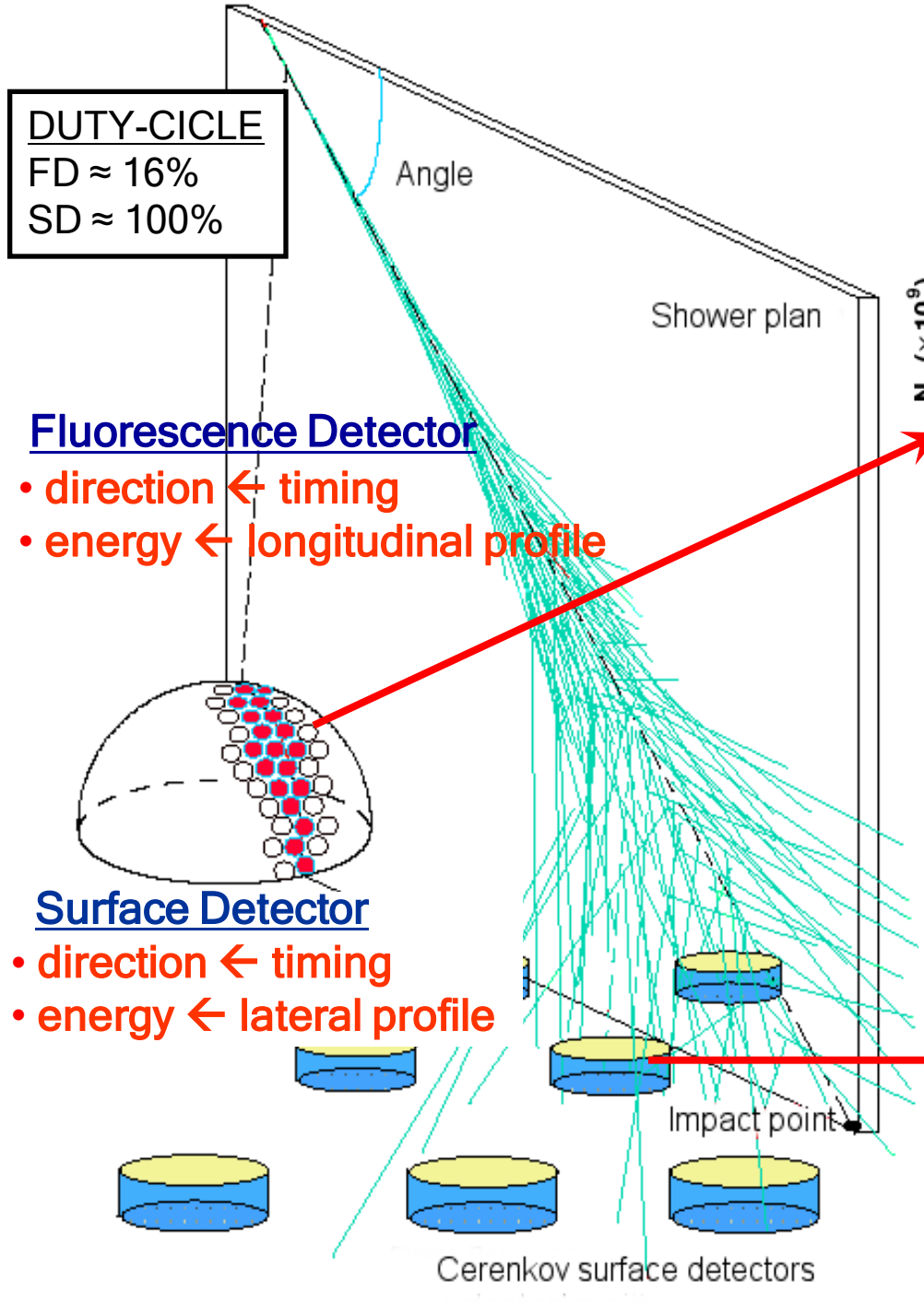






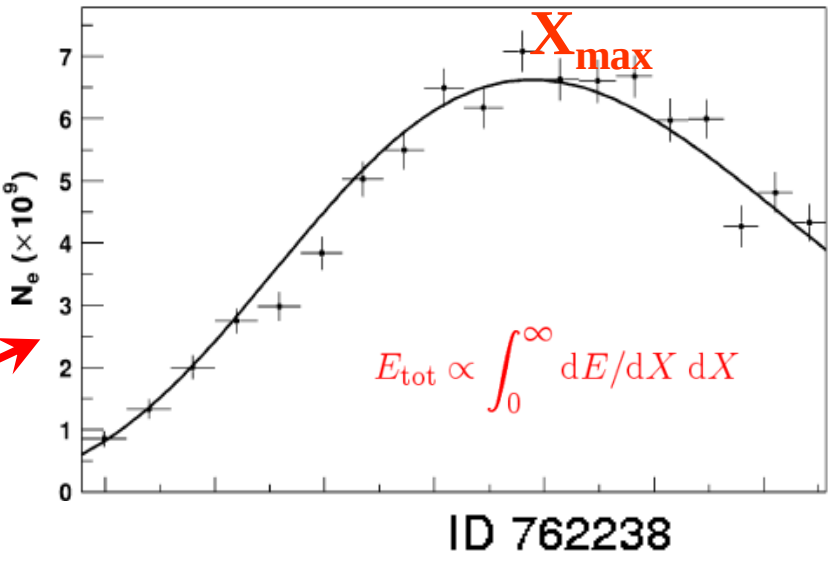
The Hybrid technique

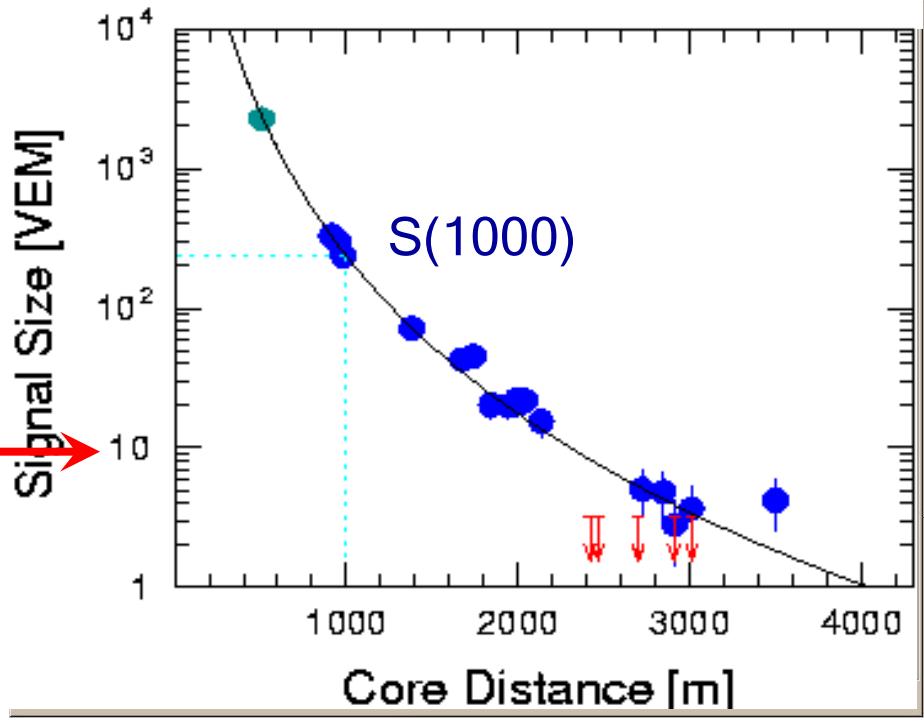
DUTY-CICLE
FD ≈ 16%
SD ≈ 100%



Fluorescence Detector
- direction ← timing
- energy ← longitudinal profile

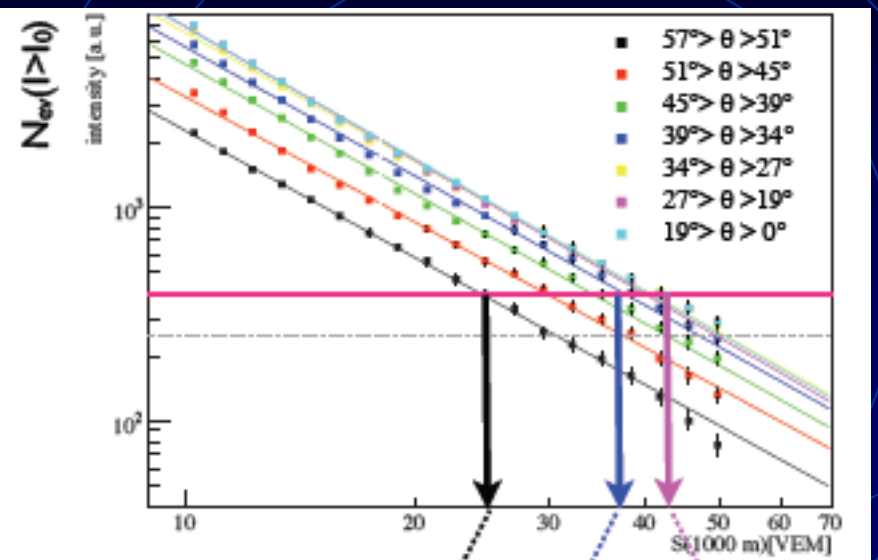
Surface Detector
- direction ← timing
- energy ← lateral profile



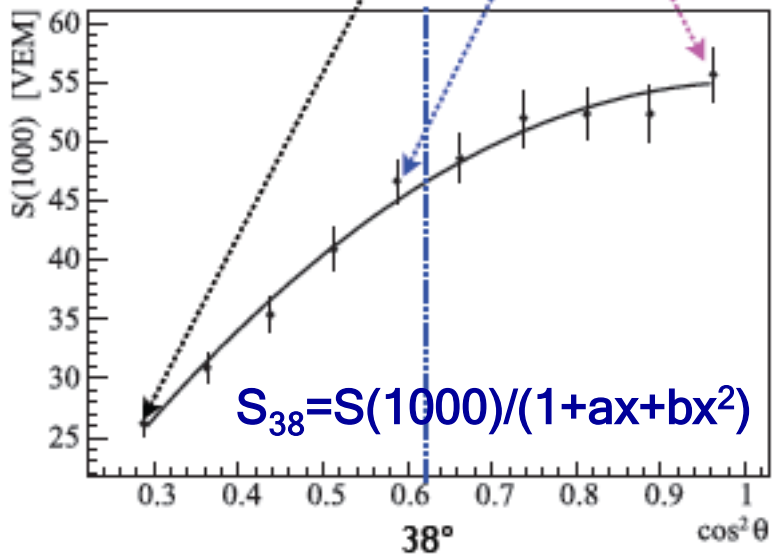


The method of FD-SD intercalibration

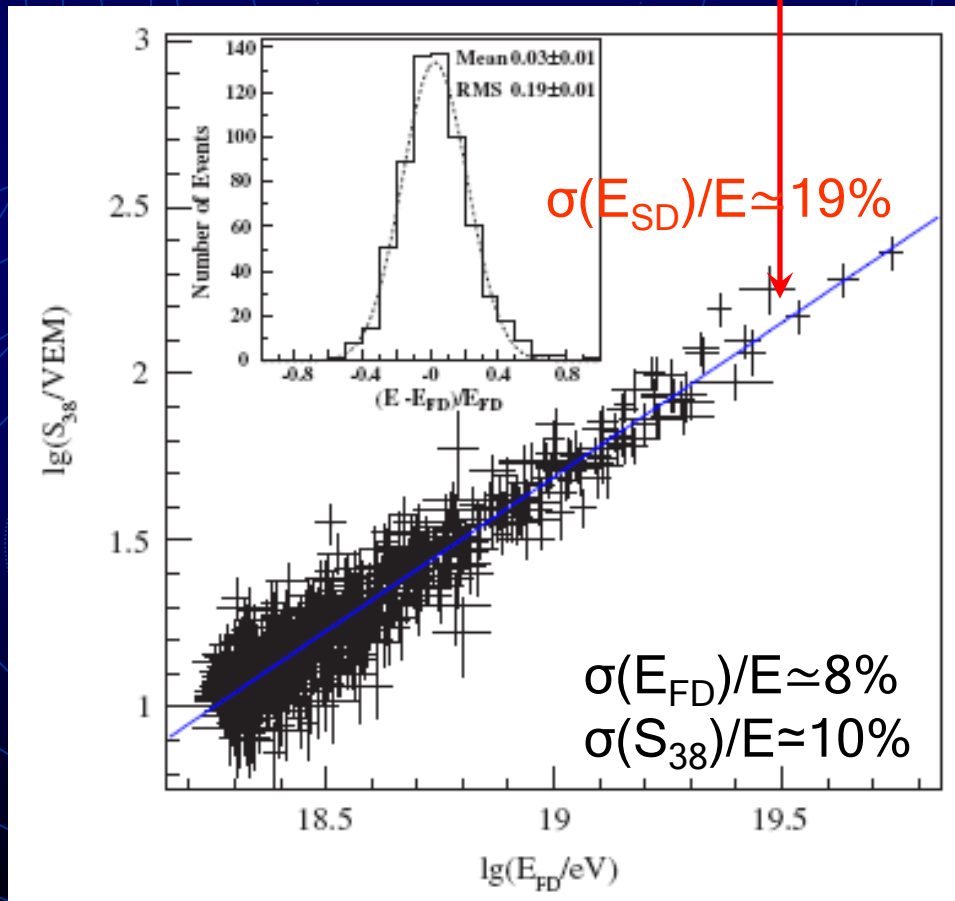
- SD Energy calibration with a subset of "golden" hybrids events



Constant intensity cut



$E_{FD} = a\ S_{38}^{\ b}$



QUESTION:
End to the cosmic ray spectrum?

(Greisen, Phys. Rev. Lett., 16 (1966) 748)

or first estimate of the Primary Cosmic Ray Energy Spectrum and its suppression

ANSWER:
YES

- The flux is strongly suppressed above 4×10^{19} eV
- A single power law hypothesis rejected with significance > 20 σ
- A break in the power law ("ankle") observed at 3×10^{18} eV

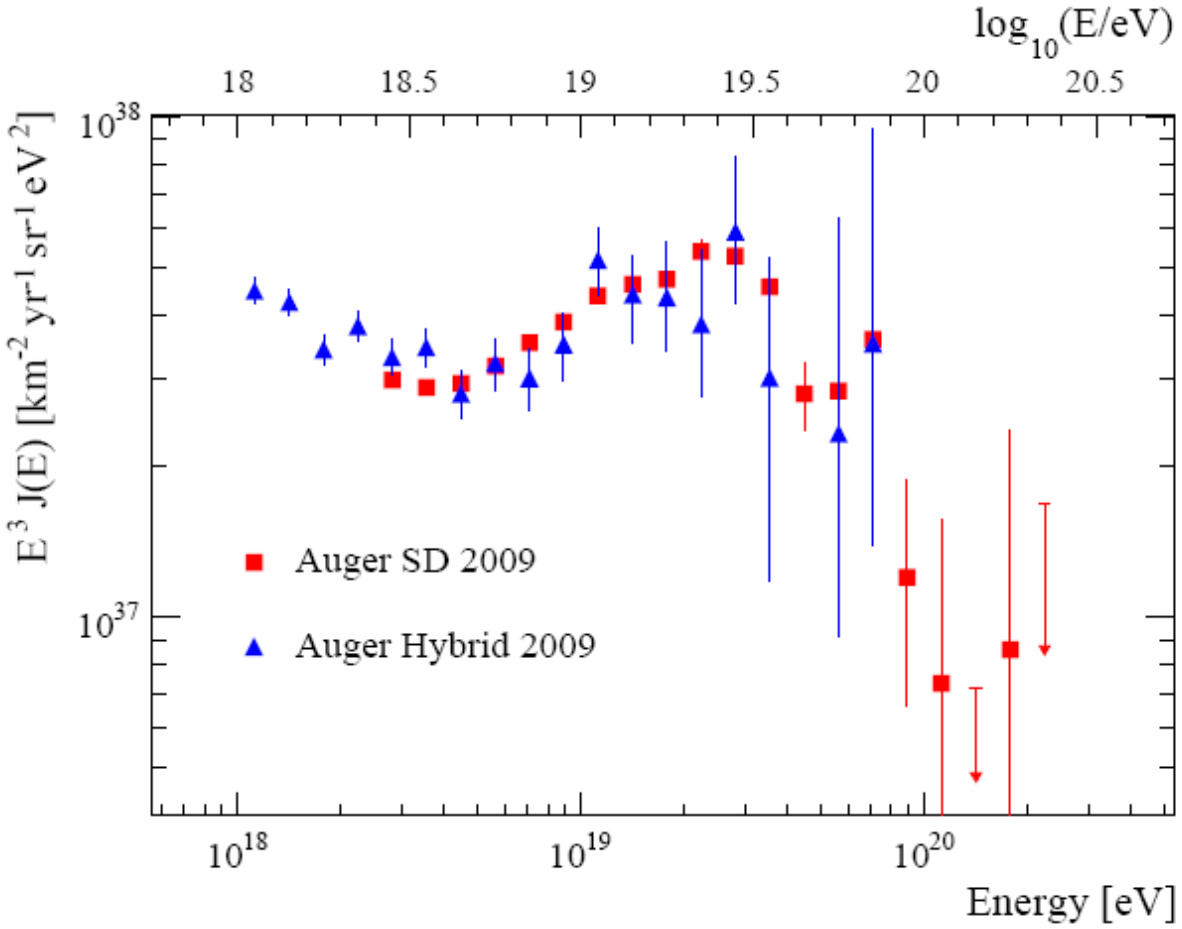
P.Auger Collaboration Phys.Lett.B 685(2010) 239
P.Auger Collaboration Phys.Rev.Lett.101,061101(2008)

The Hybrid + SD energy spectrum

Data sample:

Auger Hybrid: ≈1700 events, November 2005 - May 2008

Auger SD: > 35000 events, January 2004 – December 2008 , ε = 12790 km^{2}sr yr



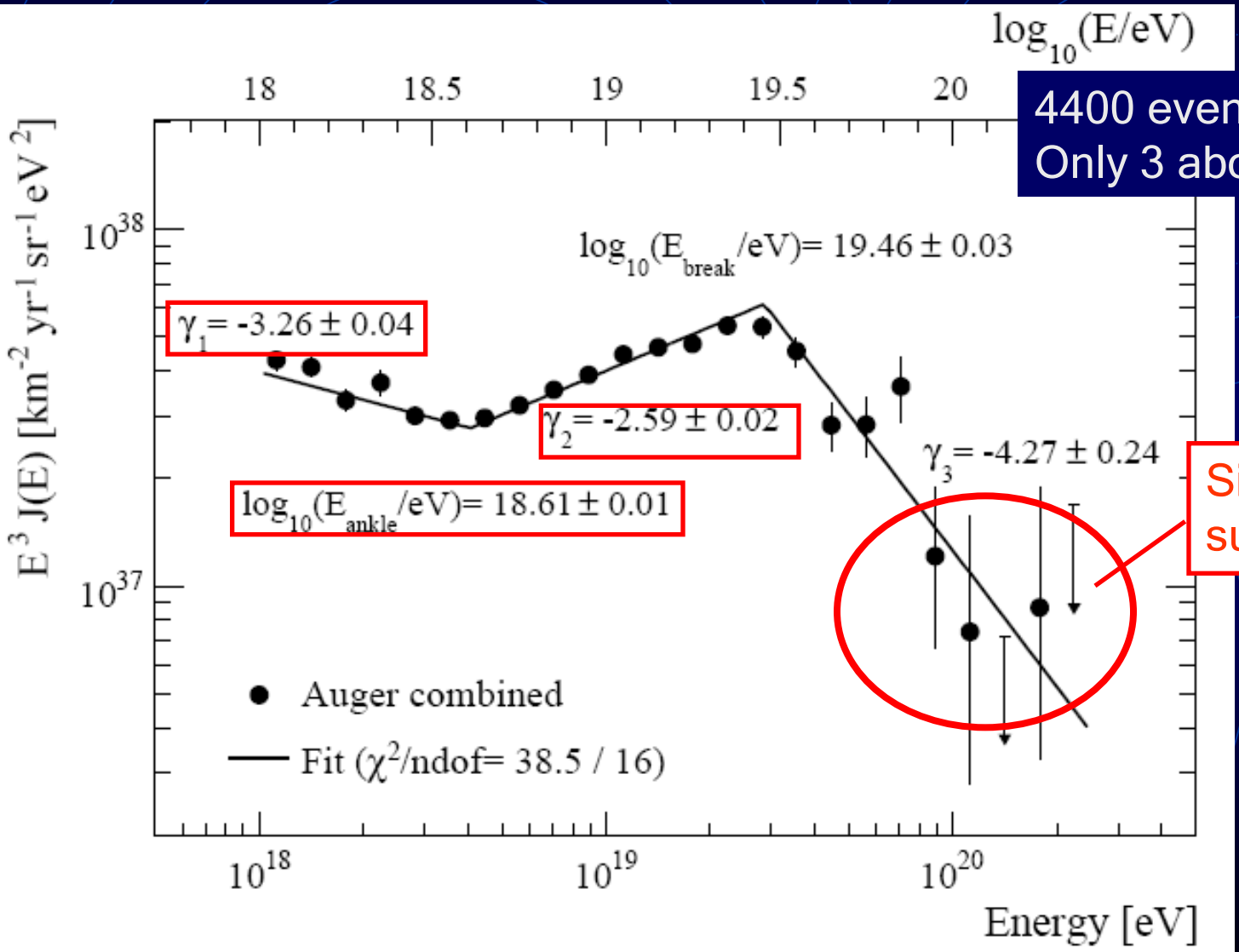
Energy uncertainty from the calibration curve:

- 7% at 10 EeV
- 15 % at 100 EeV

Overall systematic uncertainty on the absolute energy from FD: 22% (14% from the fluorescence yield!)

The combined Auger spectrum

Use of a maximum likelihood method to combine the two FD and SD spectra

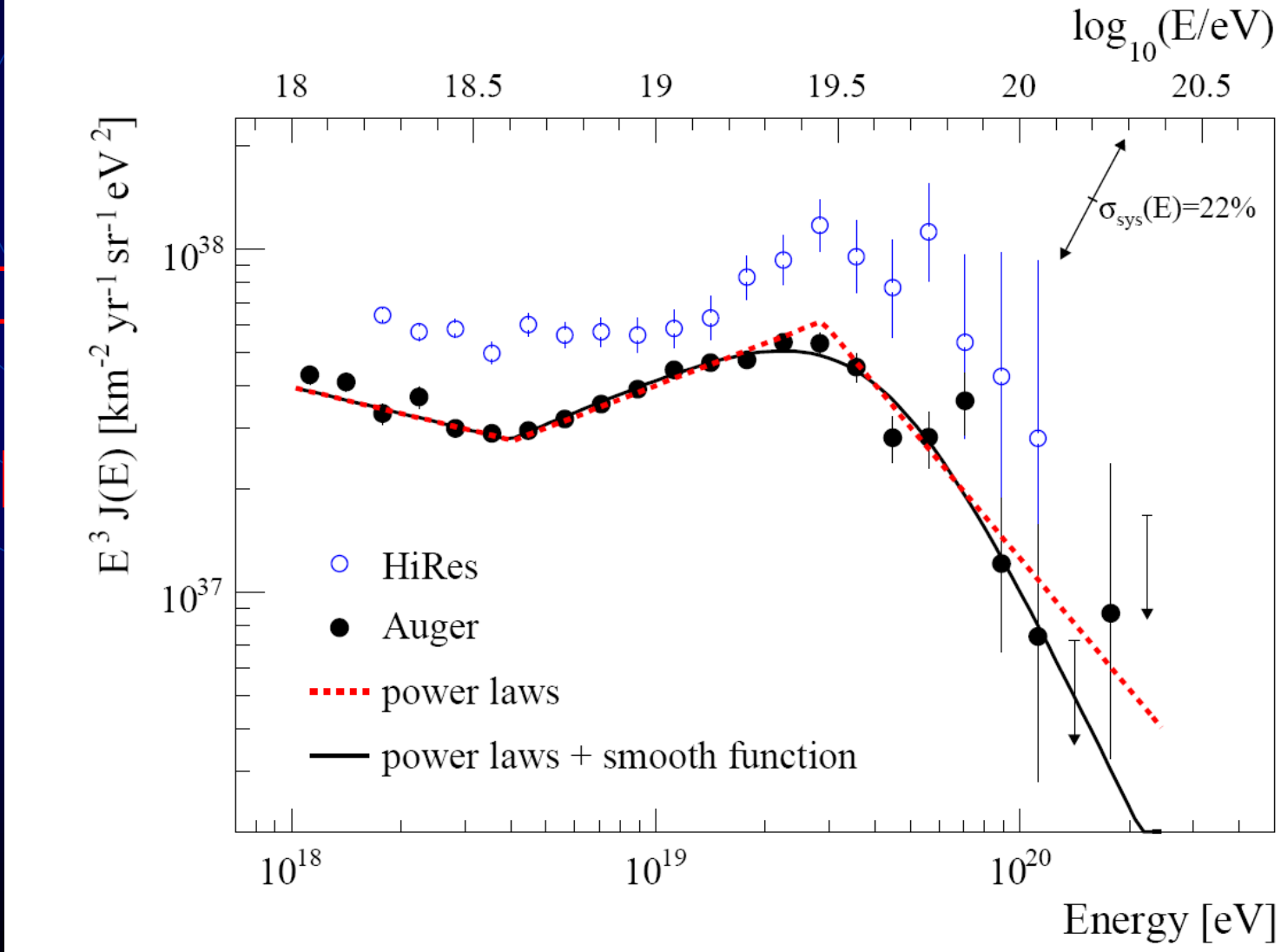


4400 events above 10^{19} eV
Only 3 above 10^{20}eV

Significance of suppression > 20σ

The combined Auger spectrum

Comparison with the HiRes spectrum



QUESTION:
Where do UHECRs come from?

or are their sources within our cosmological neighbourhood?
Anisotropy studies on small and large scale needed

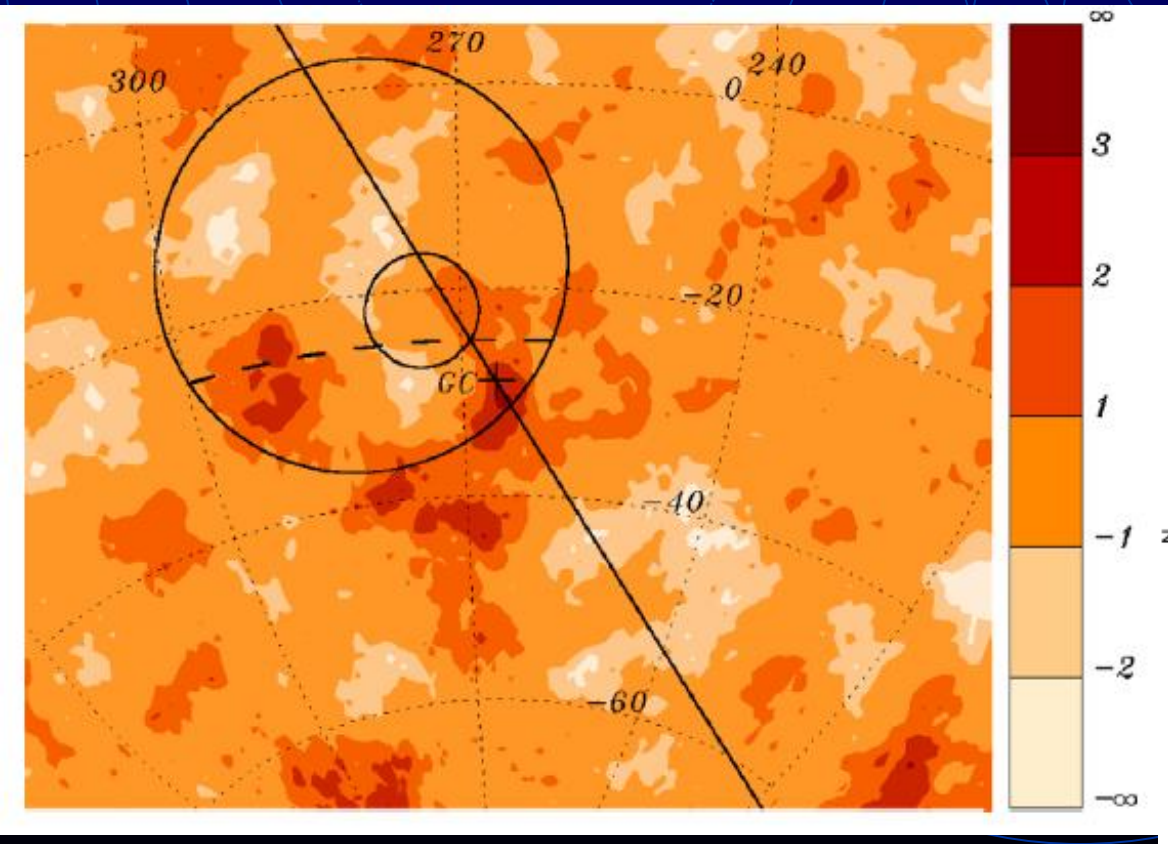
ANSWER:
We don't know yet,but ....

- No excess localized around the Galactic Centre
- First evidence of anisotropy in arrival directions E>60 EeV

P.Auger Collaboration, Astropart. Phys. 27(2007)244
P.Auger Collaboration, Science 318(2007)339
P.Auger Collaboration, Astropart. Phys. 29(2008)188
P.Auger Collaboration, submitted Astr.Phys.(June,26 2010)

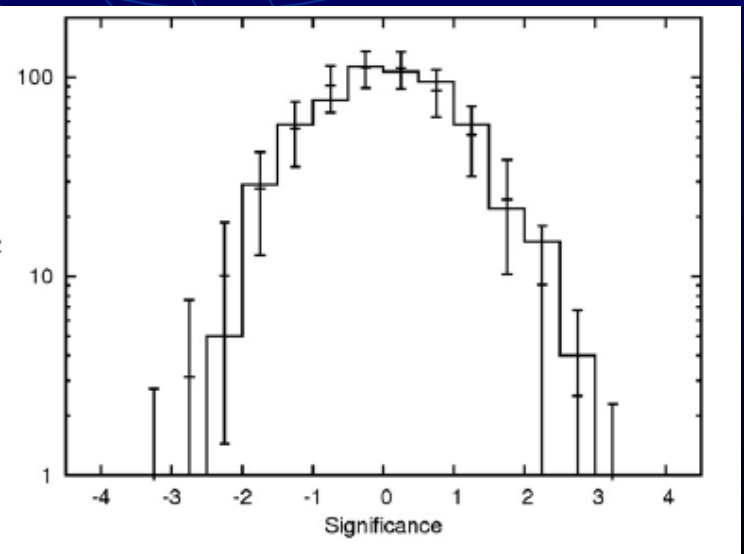
Search for excess of UHECRs from GC

- Data sample:
- January1, 2004 – March 30, 2006
- 79265 SD events with $\theta<60^\circ$, $10^{17.9}\text{eV}<E<10^{18.5}\text{eV}$
- 3439 FD events with $\theta<75^\circ$, $E>10^{17}\text{eV}$
- AUGER = 4 AGASA, AUGER = 10 SUGAR
- Determination of background from isotropic cosmic rays with 2 methods



No significant excess!

- 2116 observed events
- 2160, 2170 expected for flat distribution



Correlation with nearby extra-galactic objects

Data sample: January 1, 2004 - August 31, 2007

- 27 events, $\theta<60^\circ$, $E > 5.6 \times 10^{19}$ eV

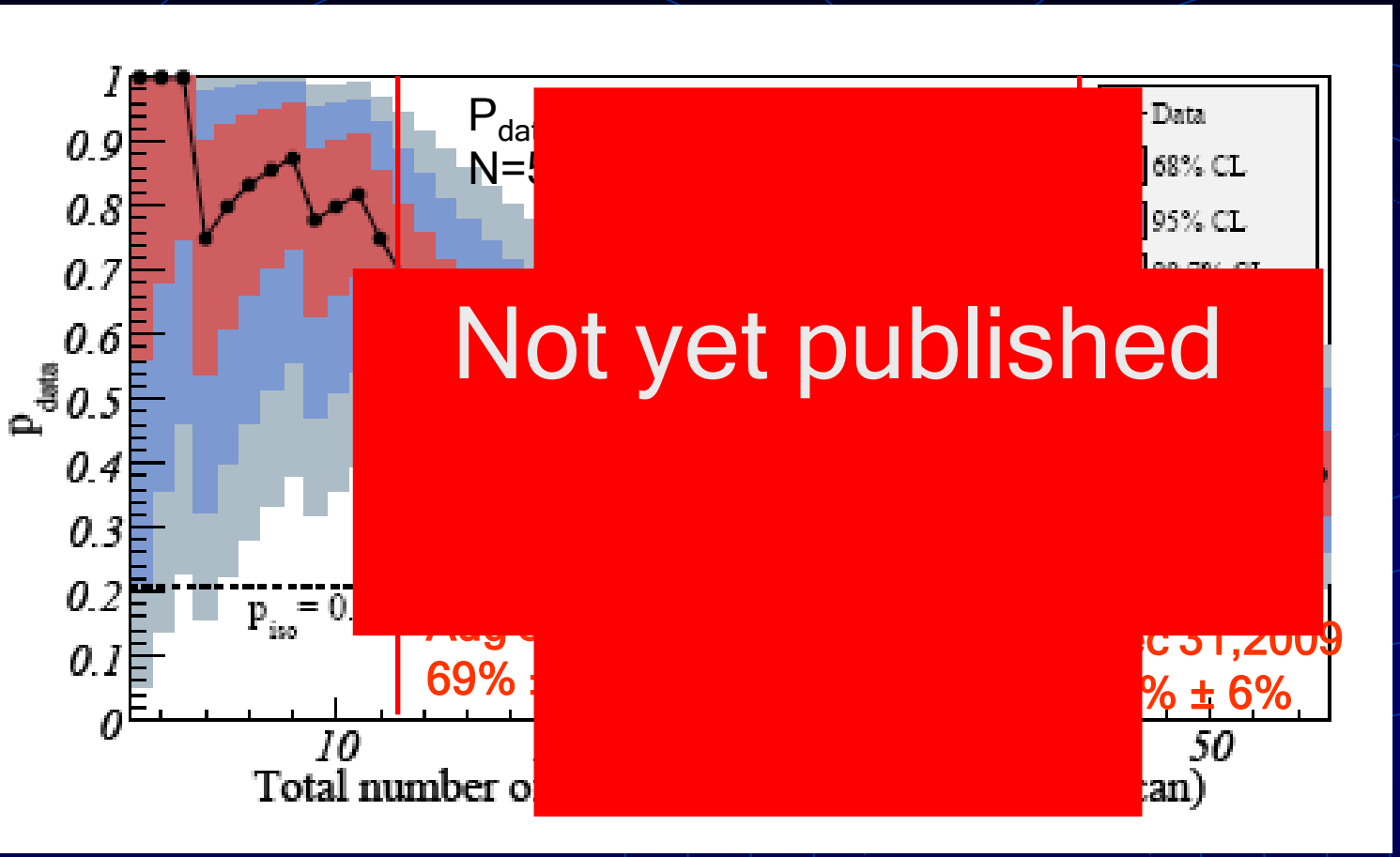
Update: up to December 31, 2009, $\varepsilon = 20370$ km^2 sr yr

- 69 events, $\theta<60^\circ$, $E > 5.5 \times 10^{19}$ eV

Correlation with nearby 318 AGNs (3.1°, <75 Mpc) of VCV catalog

Not yet published

Monitoring the correlation signal



- First scan (14 events) gave:

ψ < 3.1°, z < 0.018 (75 Mpc) and E > 56 EeV → P_{ISO}=21%

- At the present, 38% (21/55) events correlate with AGNs against 21% expected for the isotropy (Nature? catalog?)

- BUT the signal is still incompatible with isotropy at 99.7% c.l. !

QUESTION:
What is the composition of UHECRs?

Or are cosmic rays heavy or light nuclei?
Or do we understand air shower physics at ultra-high energies?

ANSWER:
??

- Change in the elongation rate around the ankle: transition from galactic to extra-galactic cosmic rays?

- A gradual increase of the mass up to E = 59 EeV: towards a heavier composition at higher energies?

P.Auger Collaboration, Phys.Rev.Lett. 104,091101(2010)

Mass composition and its observables

- Assuming Heitler's (1954) model and superposition model (Gaisser 1982): *"A nucleus of energy **E** and mass **A** is equivalent to **A** independent protons of energy **E/A**"*

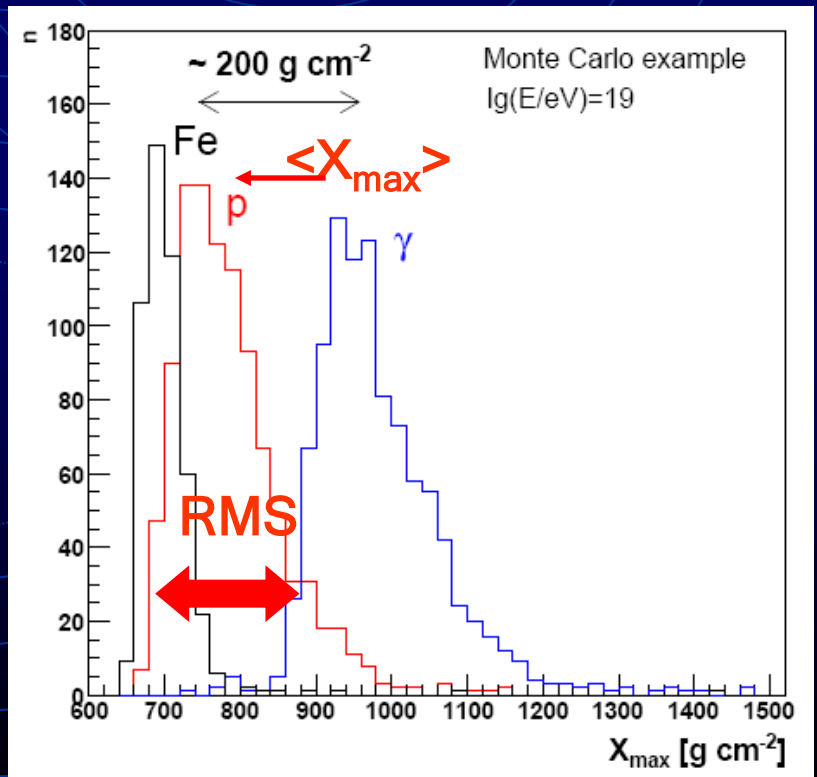
1) $$< X_{\max} >= \alpha\left(\ln E - \langle \ln A \rangle\right) + \beta$$

α, β model-dipendent coefficients

Elongation rate

2) $$D_{10} = \frac{d < X >}{d \lg E} \approx \alpha\left(1 - \frac{d < \ln A >}{d \ln E}\right) \ln(10)$$

3) *RMS (X_{max})*



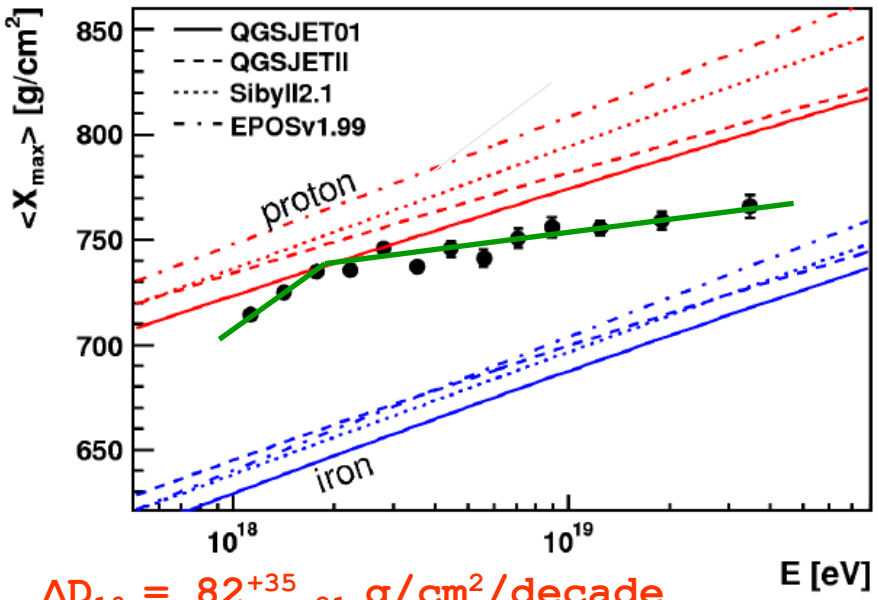
CAVEAT: the intepretation depends on the hadronic models!

Measurement of X_{max} for EAS > 10^{18} eV

- Data sample: 3754 hybrid events, December 2004-March 2009
- X_{max} resolution estimated by MC simulations: ≃20 g/cm^2
- Systematics ≤ 13g/cm^2 for X_{max} and ≤ 6 g/cm^2 for RMS(X_{max})

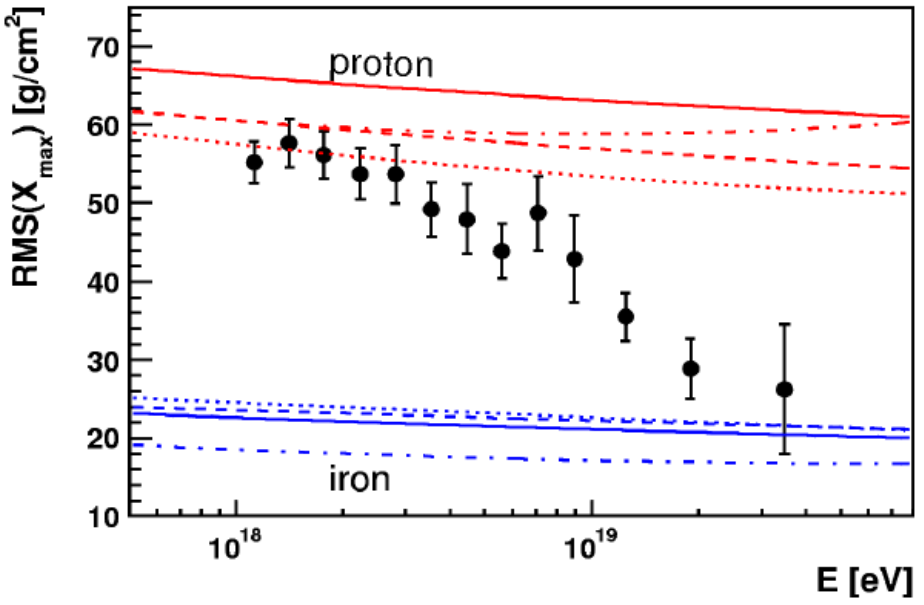
$D_{10} = 106^{+35}_{-21}$ g/cm^2/decade at $E<10^{18.24\ \pm0.05}$

$D_{10} = 24\pm3$ g/cm^2/decade at $E>10^{18.24\ \pm0.05}$



$\Delta D_{10} = 82^{+35}_{-21}$ g/cm^2/decade

Xmax RMS



QUESTION:
Are there UHE photons in our data?

Or search for primay photons and the evaluation of the photon fraction

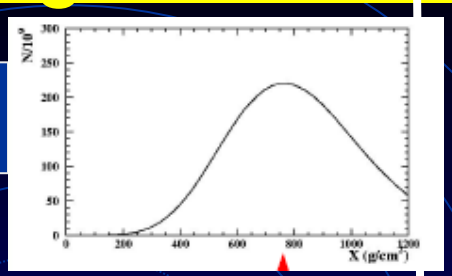
ANSWER:
No photons!

- first and only upper limit >10 EeV with fluorescence technique
- upper limit with SD improves bounds from other experiments
- the results put STRONG constraints on TOP-DOWN models

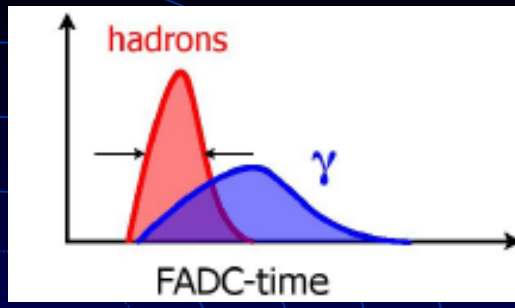
P.Auger Collaboration Astrop.Phys. 31 (2009) 399
P.Auger Collaboration Astrop.Phys. 29 (2008) 243
P.Auger Collaboration Astrop.Phys. 27 (2007) 155

Discriminating observables

FD

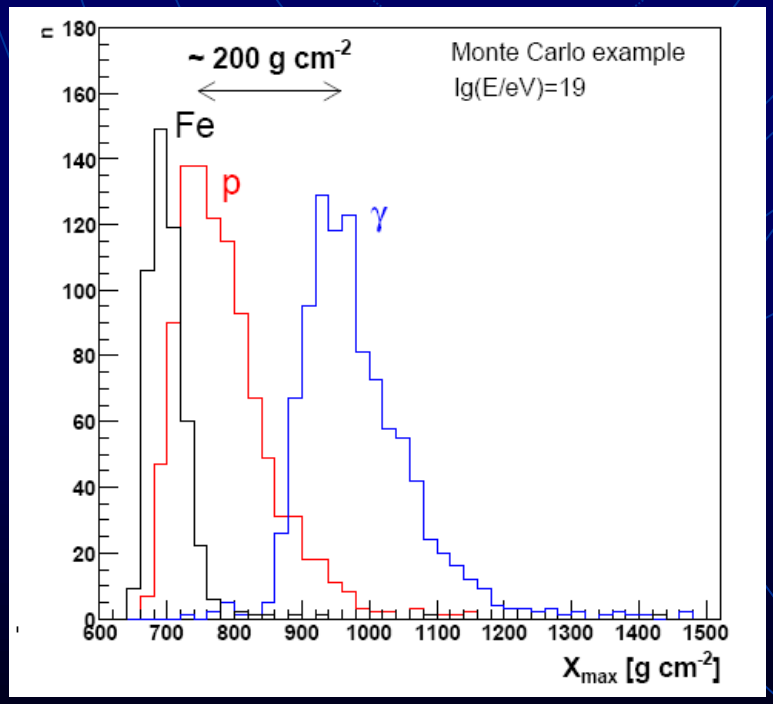


SD



Direct observation of the shower longitudinal profile

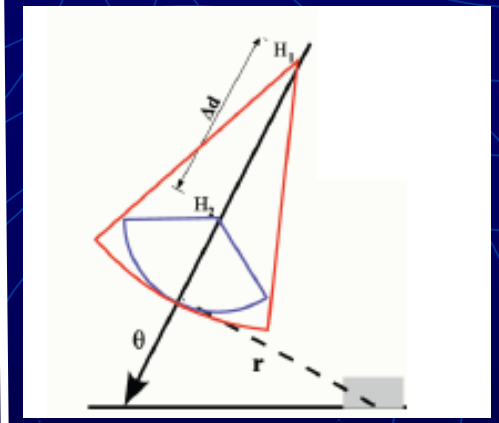
Auger Collab.Astr.Phys.27(2007)155

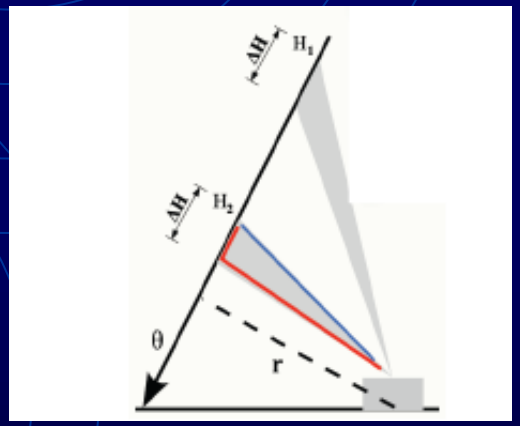


deeper depth of shower maximun X_{max}

Direct observation of the shower lateral profile

Auger Collab. Astrop.Phys.29(2008)243





For a smaller height H (larger X_{max}):

- larger delays at r

i.e. smaller radius of curvature R;

- larger spread of arrival times over ΔH_{24}

i.e. larger signal risetime;

Upper limit on the photon fraction

FD events

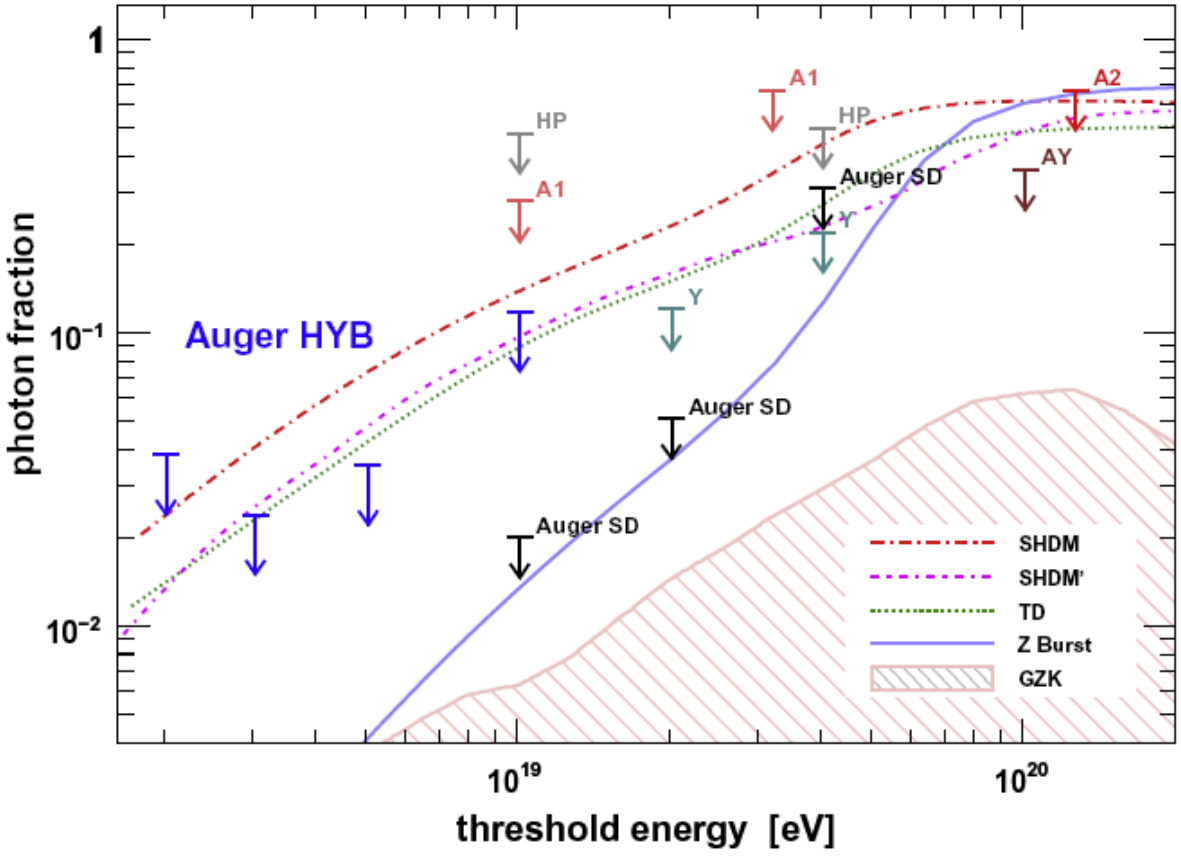
December 1,2004 - December 31, 2007

E(EeV)	#events	γ candidates	Fγ (95%c.l.)
2	2063	8	3.8 %
3	1021	1	2.4 %
5	436	0	3.5 %
10	131	0	11.7 %

SD events

January 1,2004 - December 31, 2006

E (EeV)	#events	Fγ (95%c.l.)
10	2761	2.0 %
20	1329	5.1 %
40	372	31.0 %



Auger Hybrid:
Auger Collaboration '09

Auger SD:
Auger Collaboration '08

HP: Ave et al. '00 & '02
A1: Shinozaki et al. '02
A2: Risse et al. '05
AY: Rubtsov et al. '06
Y: Glushkov et al. '07

SHDM, TD, Z Burst:
Gelmini et al. '05

SHDM': Ellis et al. '06

GZK: Gelmini et al. '07

Conclusions

- *Pierre Auger Observatory completed in 2008 and in data taking so far.*
- *The power of hybrid technique: joined use of fluorescence telescopes and surface stations*
- *About 6 years of data (million cosmic ray events) acquired and analysed.*
- *Unique results on Energy Spectrum, Mass Composition, Anisotropy on small and large scale, Photon and tau Neutrino Upper Limits.*
- *No exhaustive answers, open and intriguing questions still present…*
- *But coming soon new results: we are only waiting for new so rare events and we will go on collecting data…for the next 15 years!!*