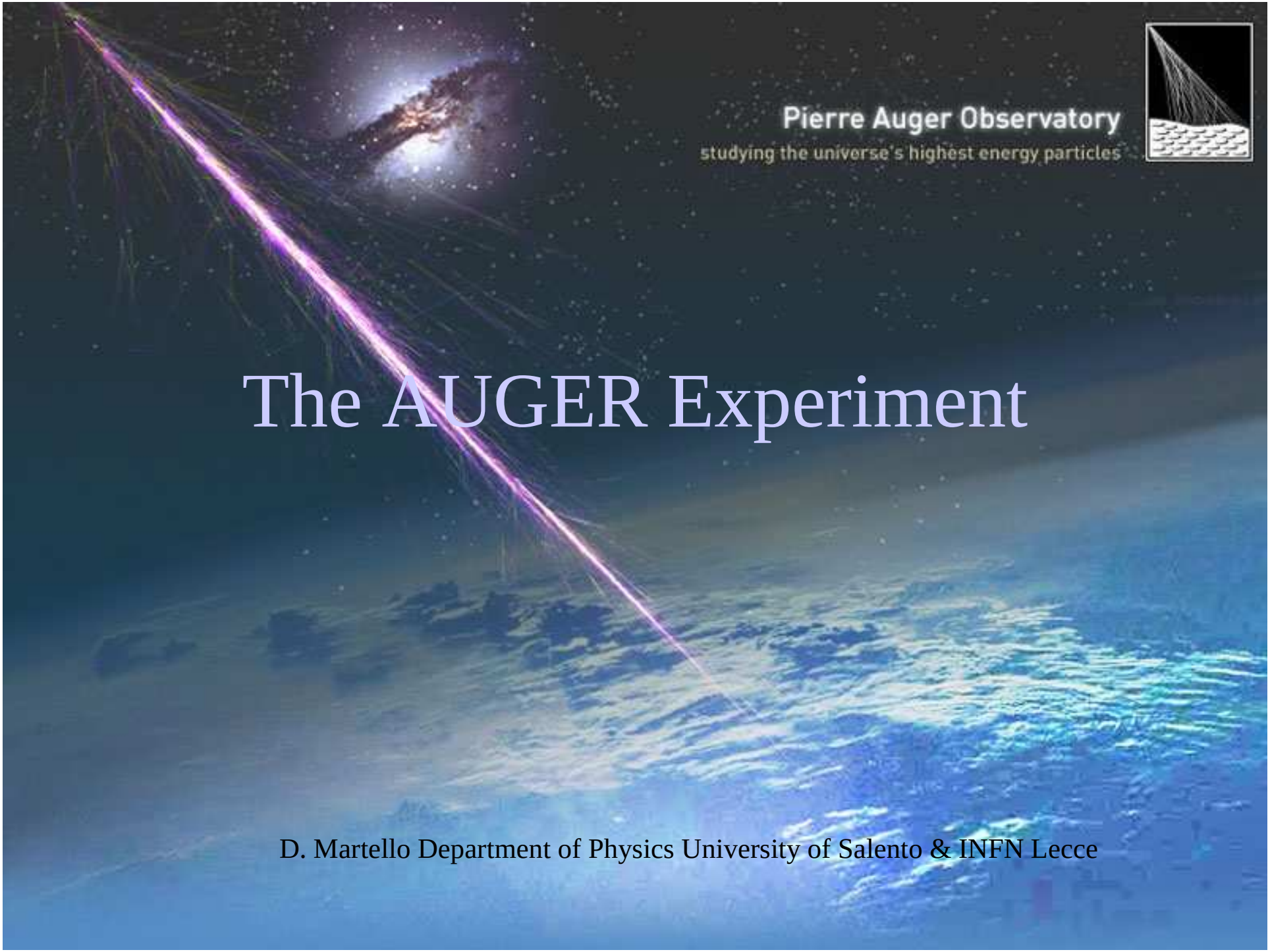


The AUGER Experiment

D. Martello Department of Physics University of Salento & INFN Lecce

The Pierre Auger Collaboration

Argentina
Australia
Bolivia
Brazil
Croatia
Czech Rep.
France
Germany
Italy
Mexico
Netherlands
Poland
Portugal
Slovenia
Spain
UK
USA
Vietnam

18 Countries
91 Institutions
~ 463 members

Auger: unprecedented statistics and precision

≈ 3000 evts/yr with $E > 10^{19}$ eV

Hybrid Detector:

Array of 1600 water Cherenkov detectors

covering 3000 km^2

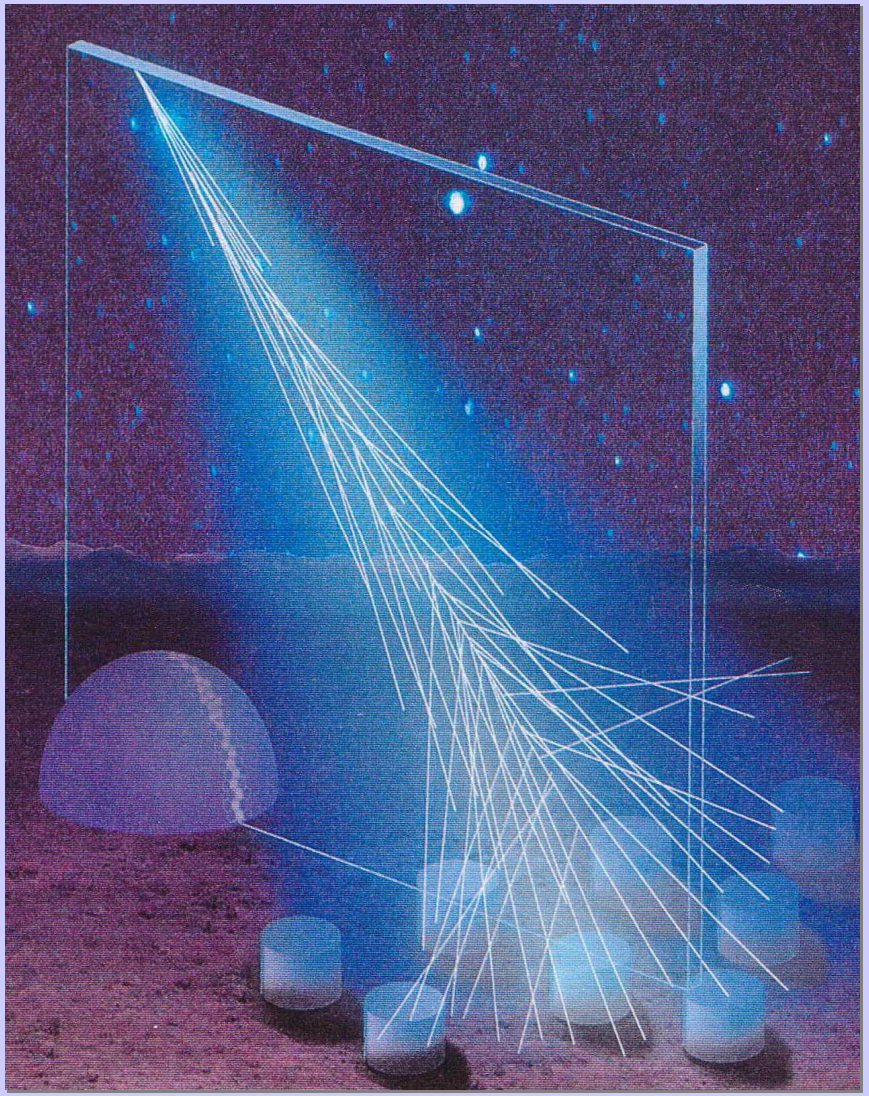
duty cycle: 100%

Fluorescence telescopes

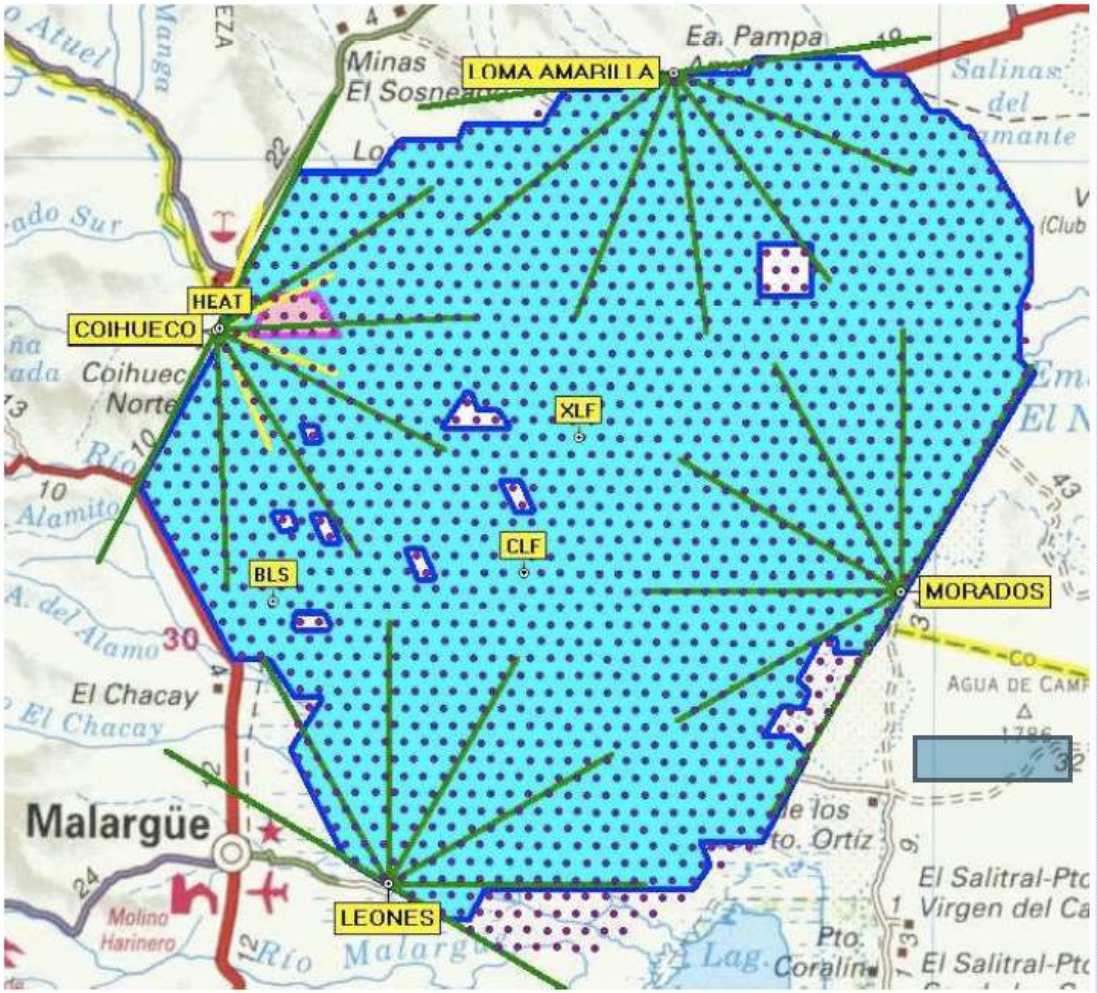
24 FDs (30^ox30^o each)

duty cycle: 10%

Better geometric reconstruction, cross-calibration, control of systematic.

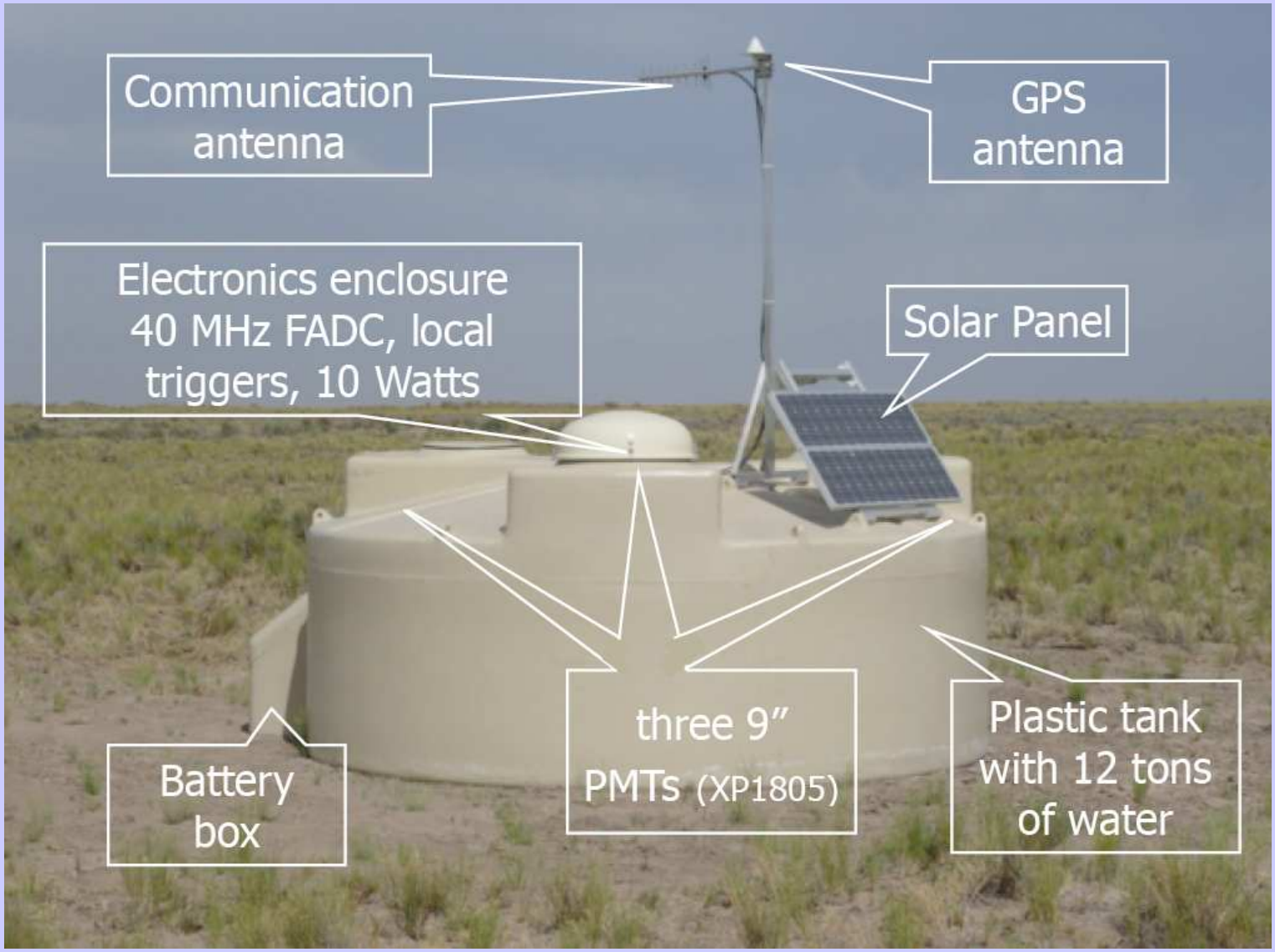


The Auger South Detector

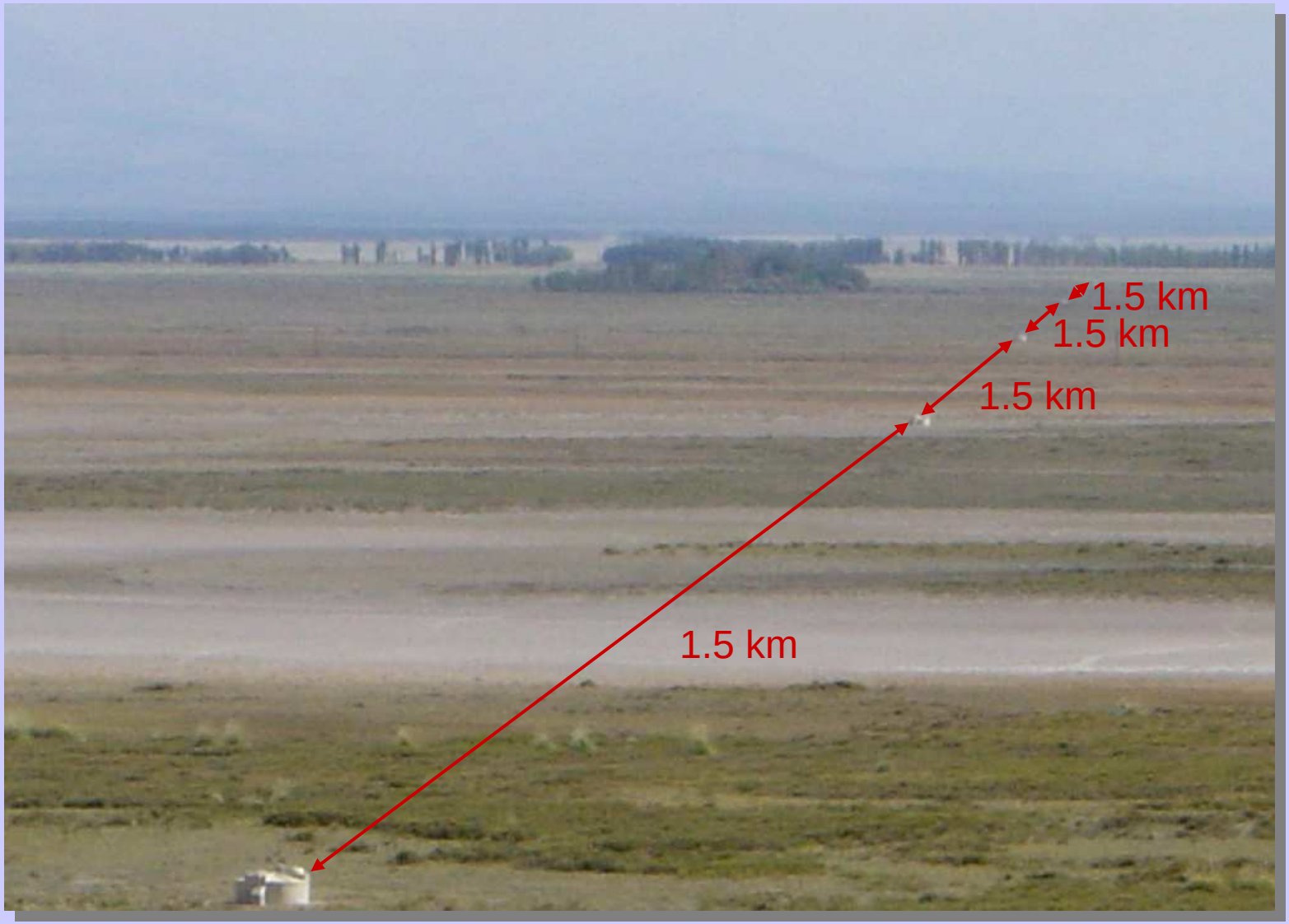


~ 60 km

The Surface Detector



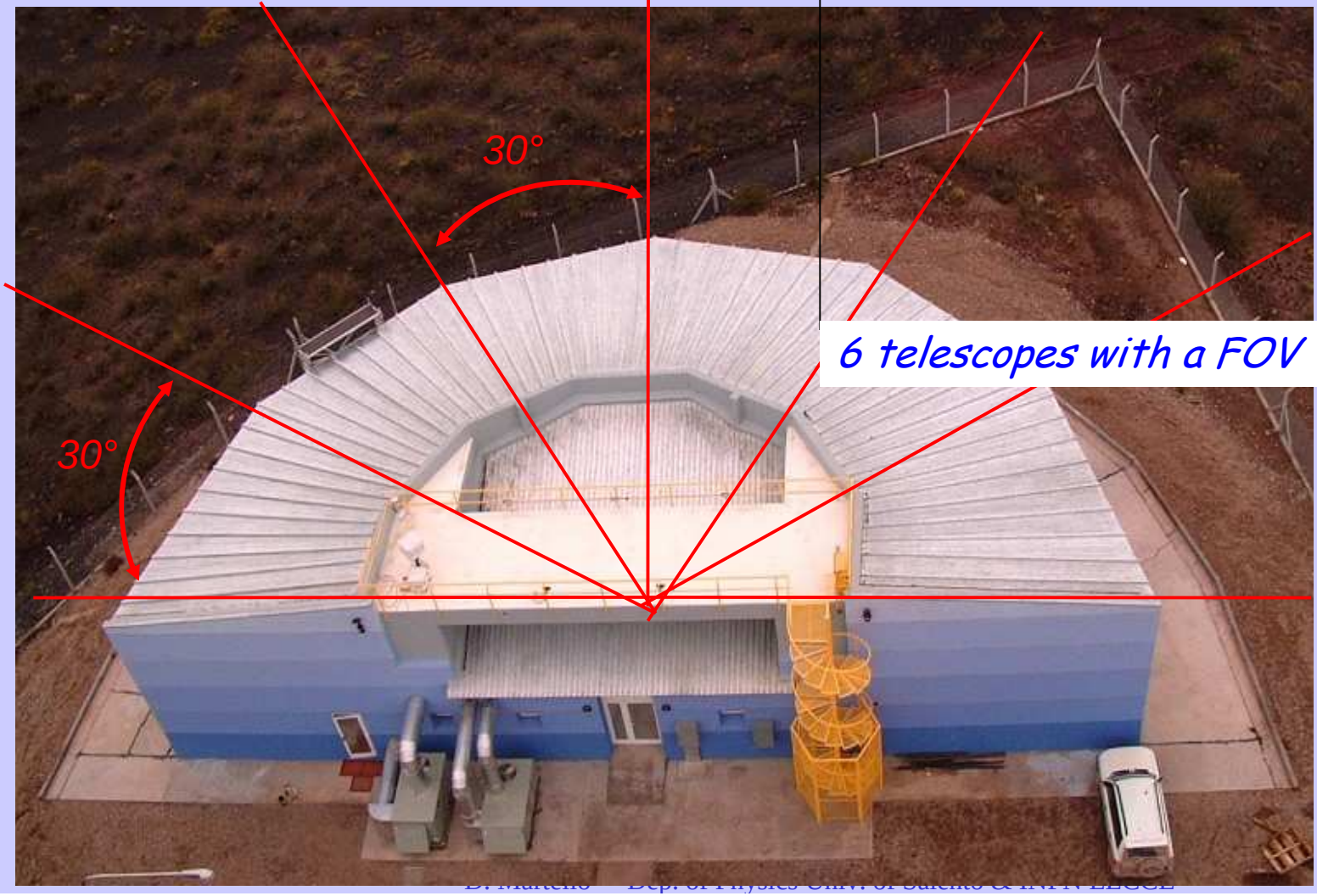
The Surface Detector (SD)



The Surface Detector (SD)

The Fluorescence Detector (FD)

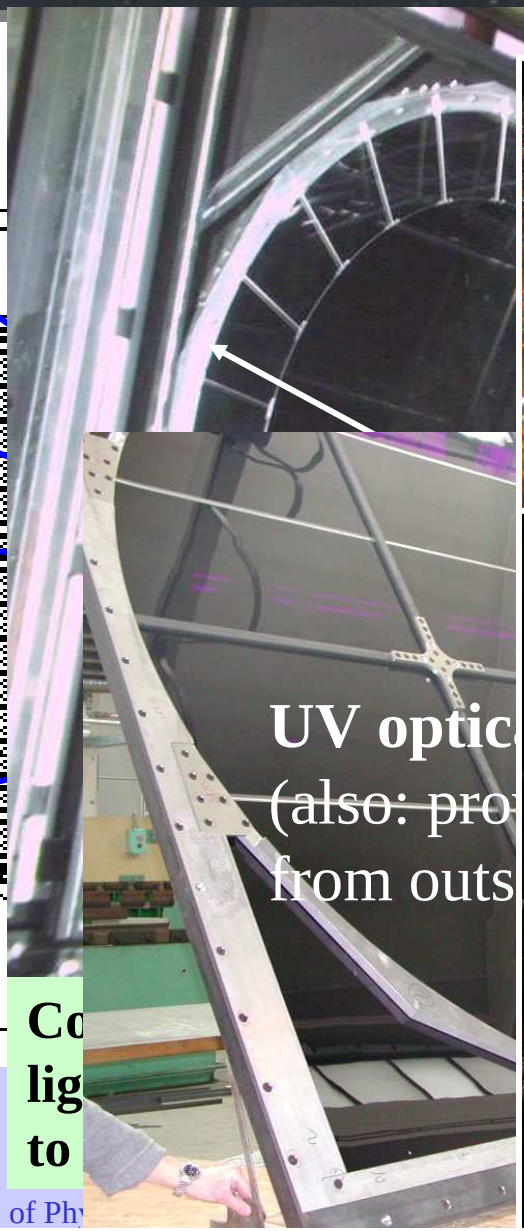
The Fluorescence Detector (FD)

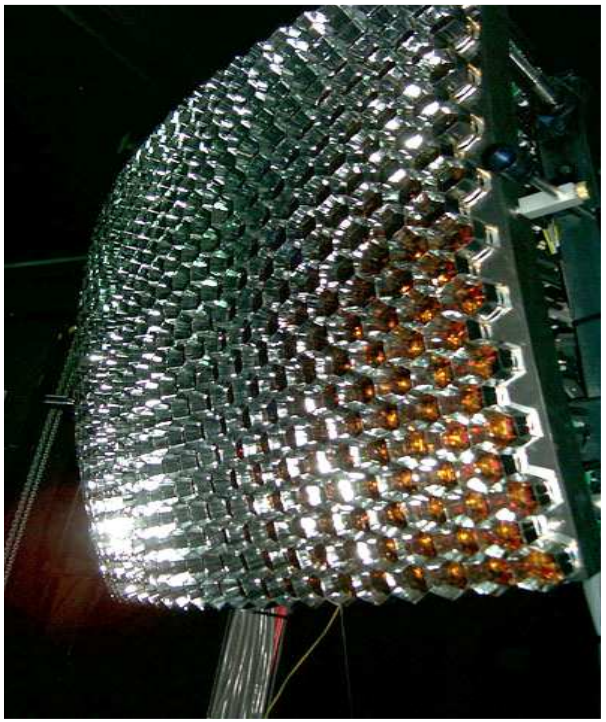


6 telescopes with a FOV of 30° x 30°

The Telescope FD

- corrector ring (2.2 m)
- UV Filter
- 3.4m mirror
- Camera with a FOV 30ºx30º





UV optic
(also: pro
from outs

Co
lig
to

Duty cycle 10%

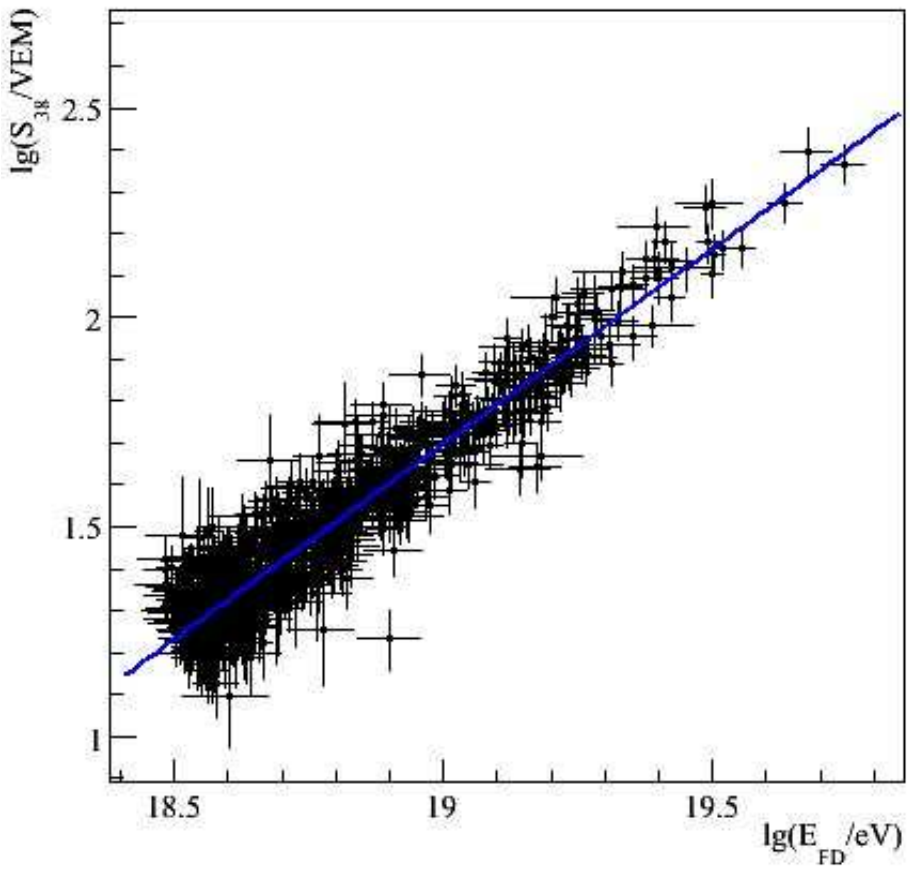
FD vs SD

	SD-only	FD-only	Hybrid
Duty-cycle	~100%	~10%	~10%
Angular resolution	1-2 deg	3-5 deg	0.2 deg
Energy	C & M depend	independent	independent
Aperture	independent	E, C, M depend	independent
Energy Thr.	~$10^{18.5}$ eV	~$10^{17,5}$ eV	~10^{18} eV

E = Energy, M = Interaction Model, C = Composition

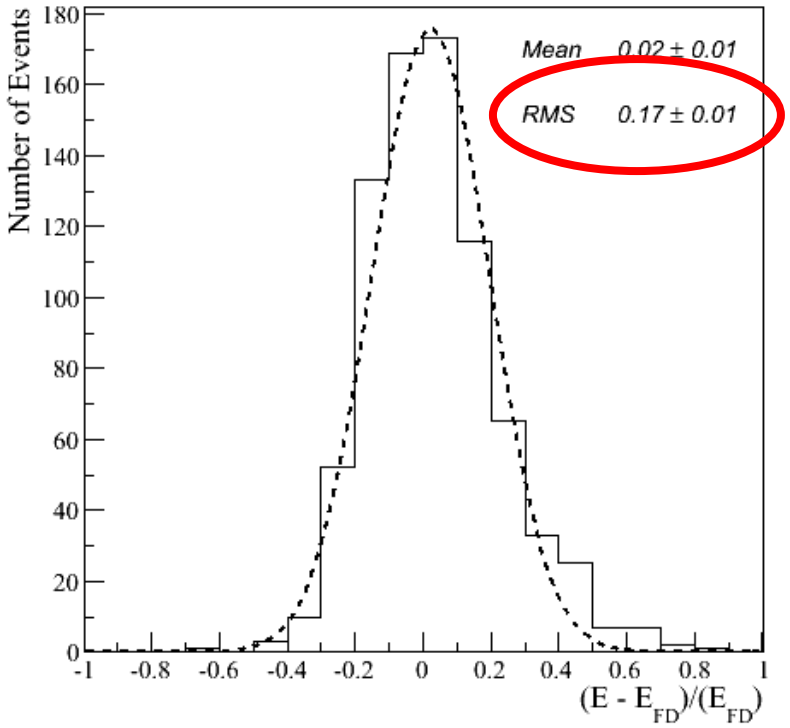
SD Calibration

Hybrid events used to calibrate SD detector



795 high quality hybrid events

Energy resolution 17 %

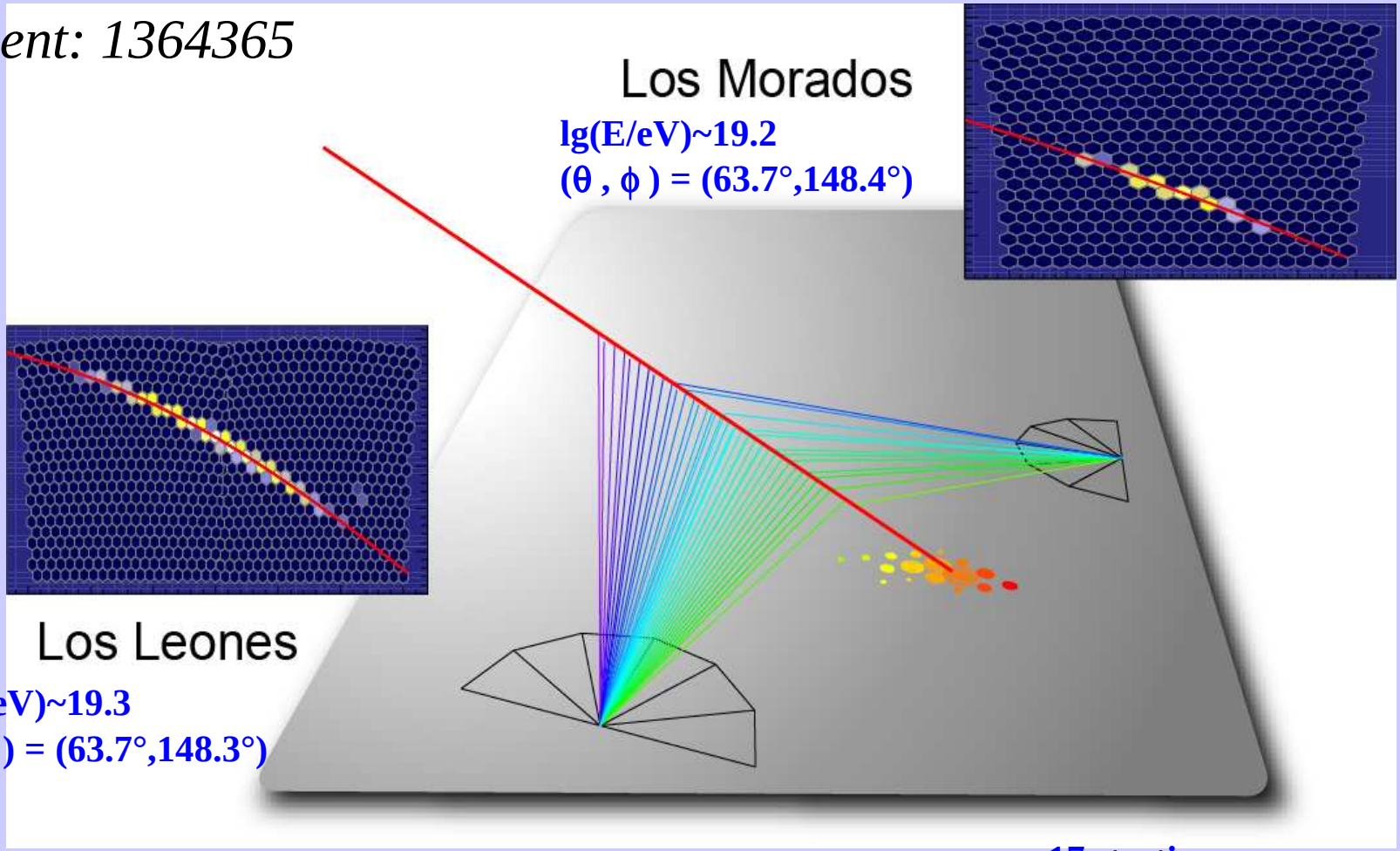


$$E = a \times (S_{38^\circ})^b$$

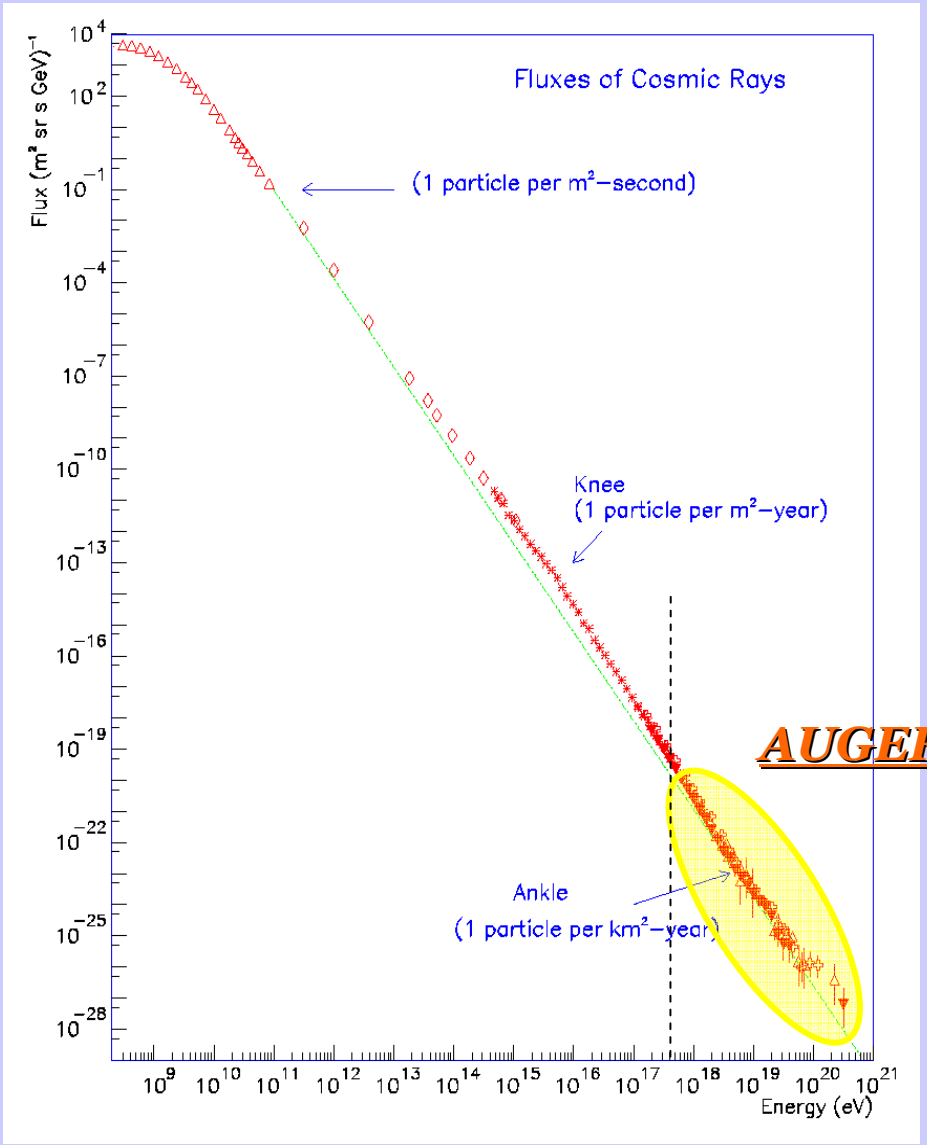
$$b = 1.07 \pm 0.04$$

Stereo Hybrid Event

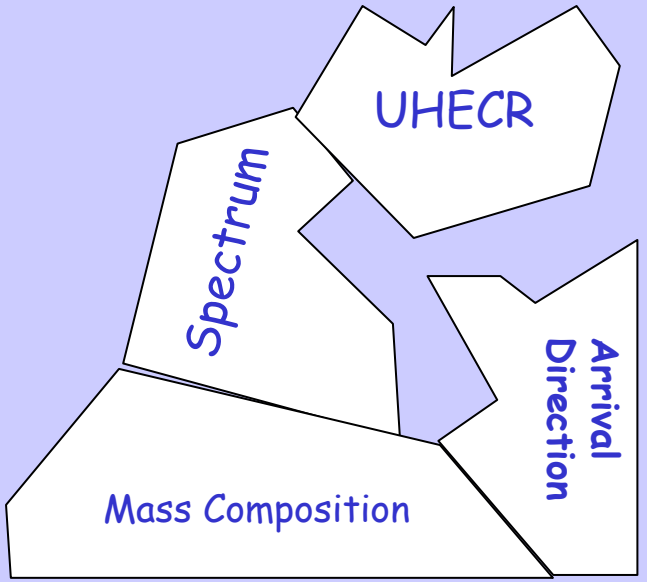
Event: 1364365



The UHECRs

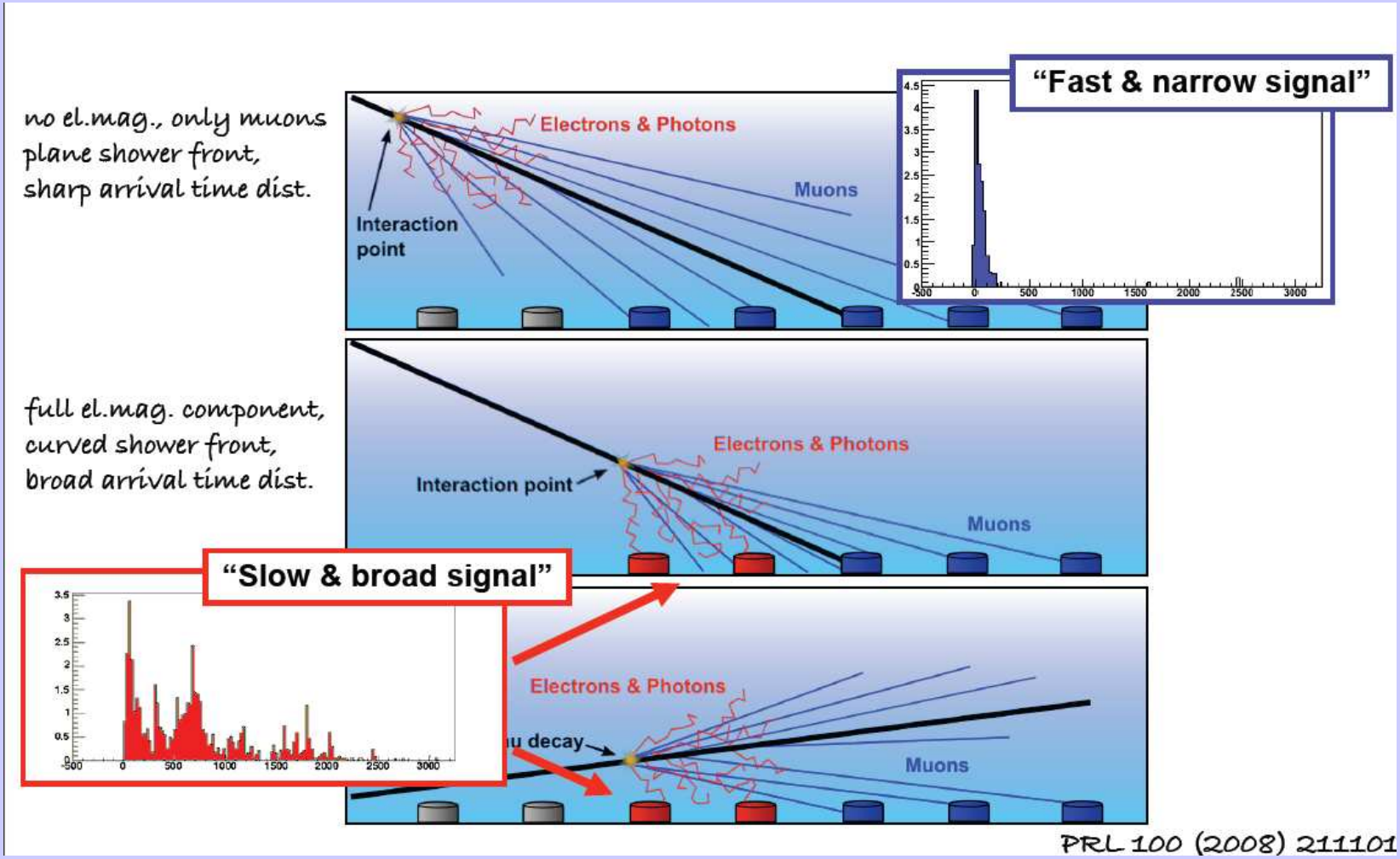


Shape of the spectrum? Cut-off?
Anisotropy in arrival directions?
Mass composition ?



Are the UHECR Charged "Standard" Particles?

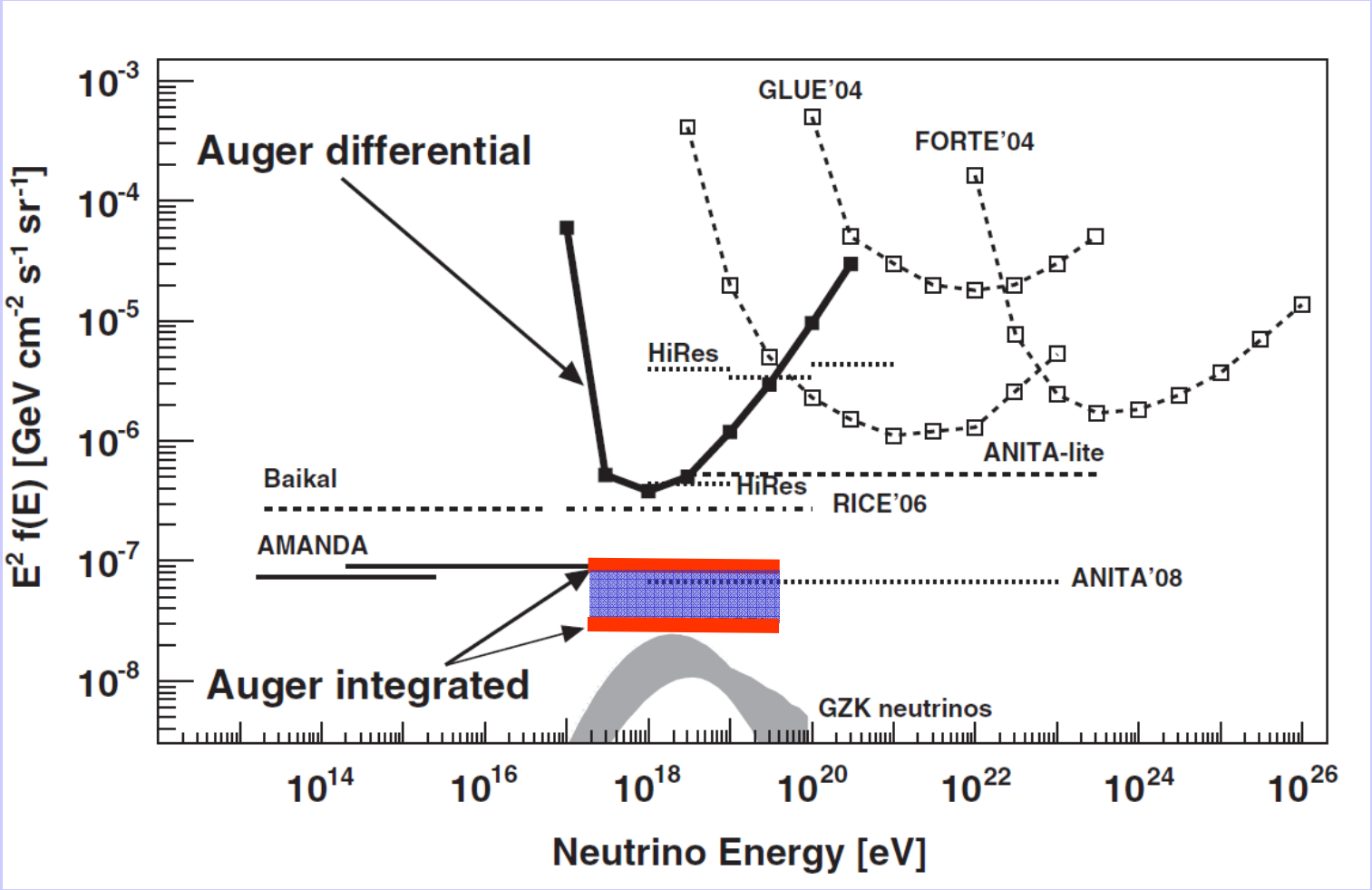
Neutrino detection with AUGER



Phys. Rev. D 79 102001 (2009)

Particles Type

No neutrino like events detected!



Particles Type

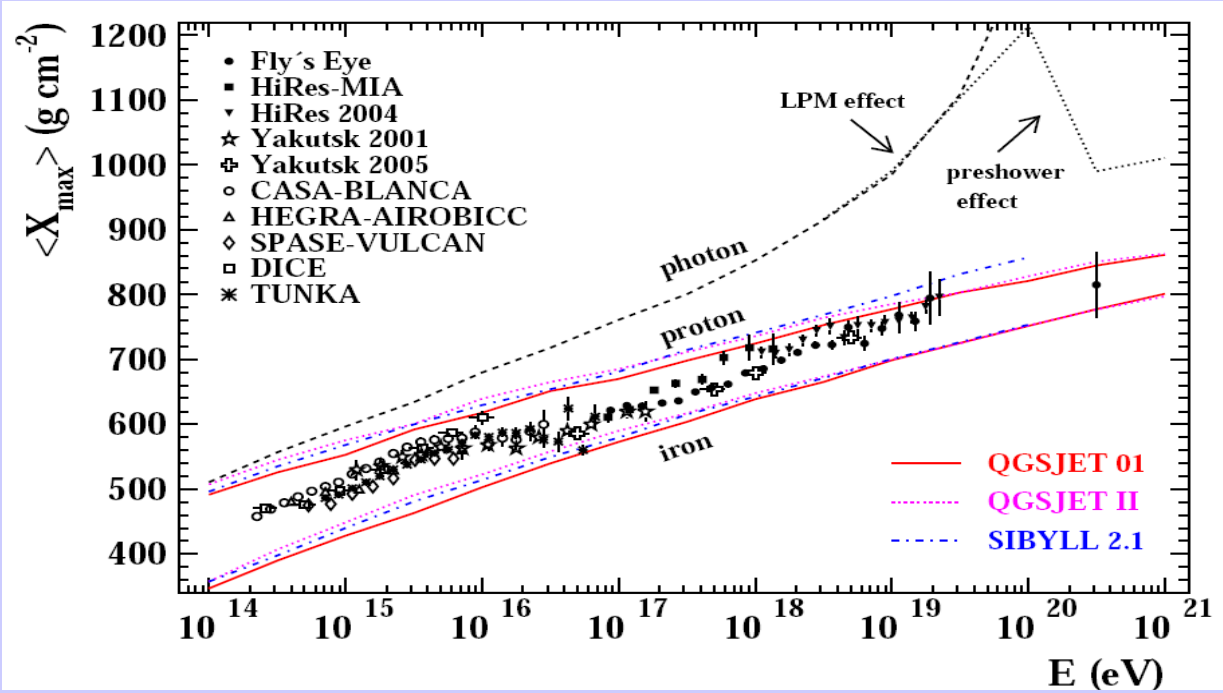
Identification of Photon Induced Showers

Depth of shower maximum (Xmax)

Fluorescence Detector

Astrop. Phys. 31 (2009) 399

Photon-induced shower is expected to develop deeper

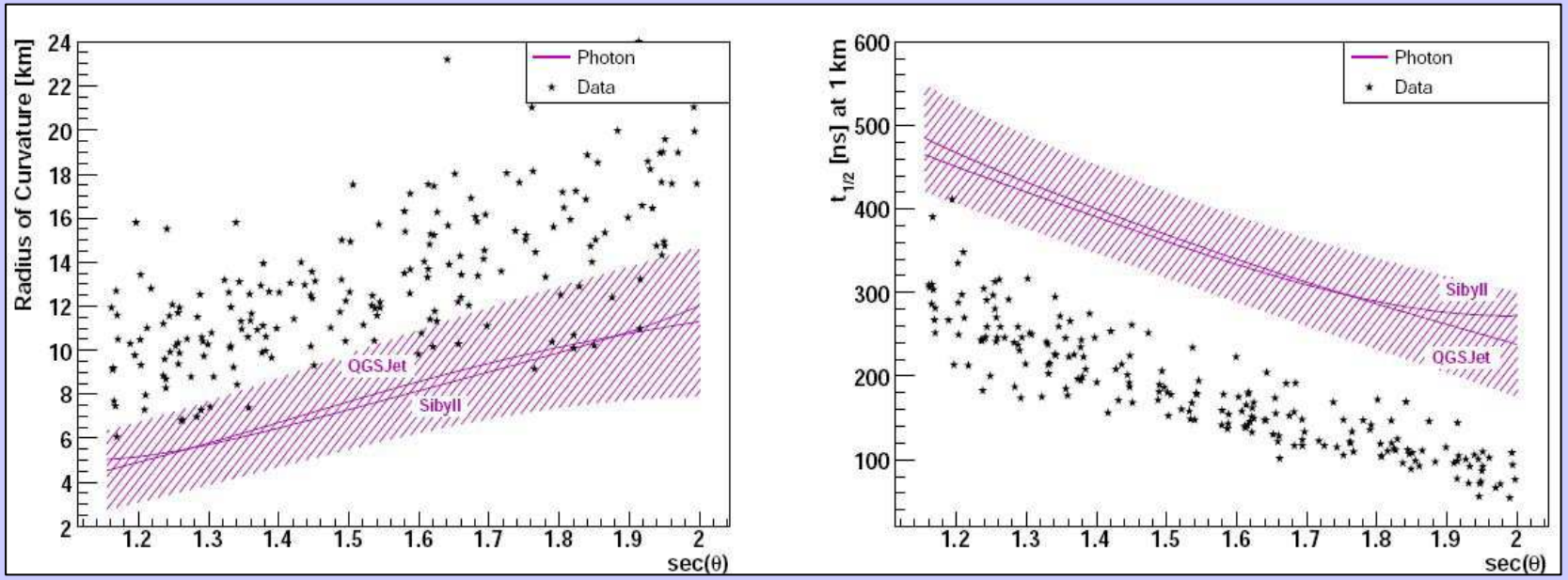


Smaller radius of curvature
Higher rise-time of the detector signal
Smaller number of muons (Nμ) at ground

Astrop. Phys. 29 (2008) 243

Surface Detector

Searching for photons: the SD side

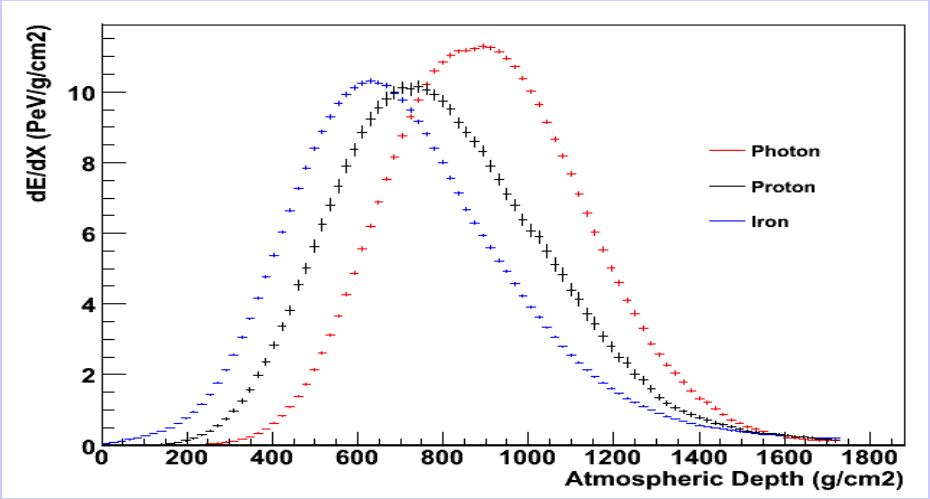


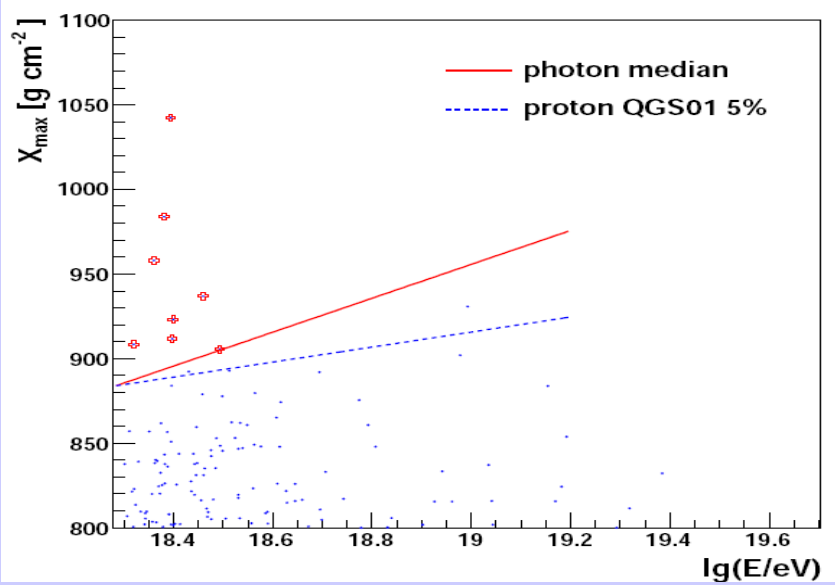
No photon candidates!

$E_{\min}$	N_γ	$\mathcal{N}_\gamma^{0.95}$	$N_{\mathrm{non}-\gamma}$	ε	$\mathcal{F}_{0.95}$
10	0	3.0	570	0.53	2.0%
20	0	3.0	145	0.81	5.1%
40	0	3.0	21	0.92	31%

Searching for photons: the FD side

Search for events with deep **Xmax**

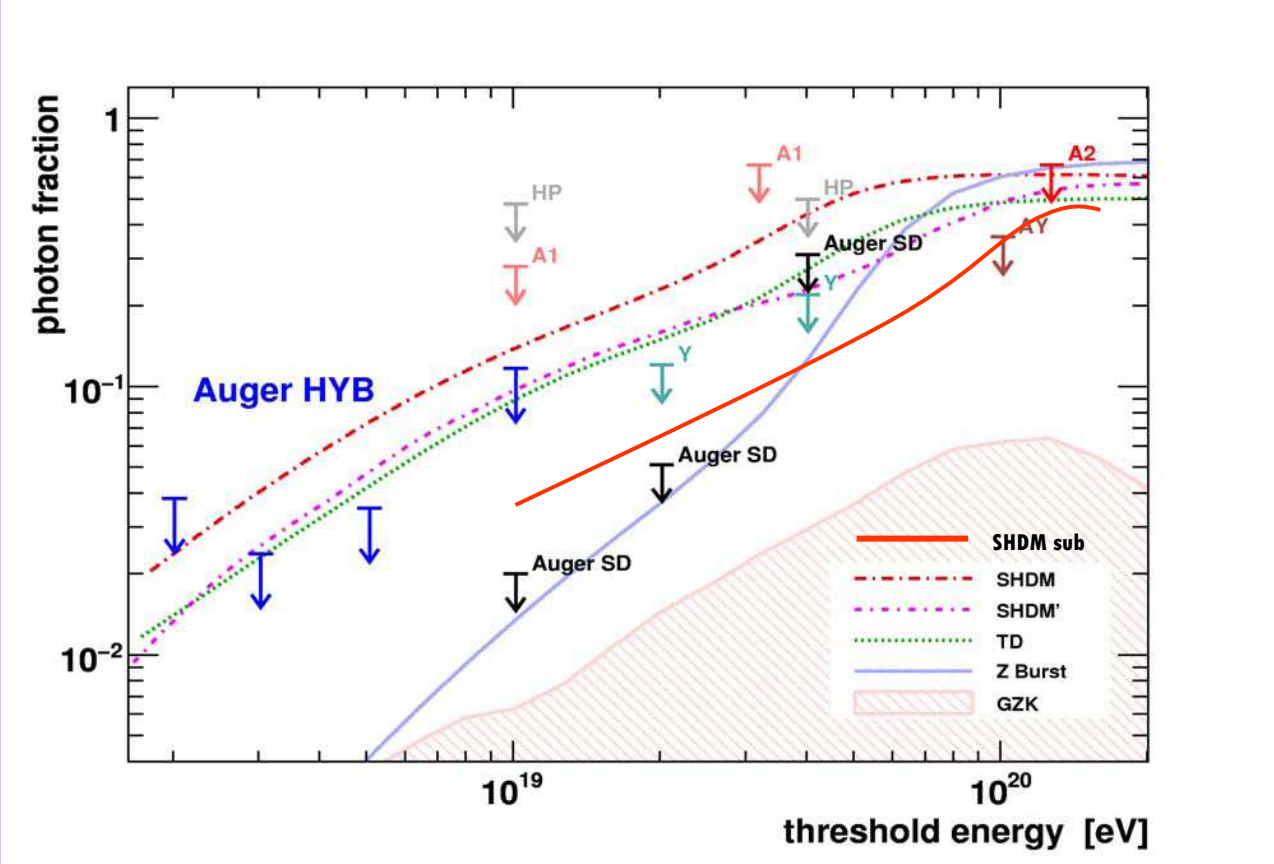




8 photon candidates at E>2 EeV

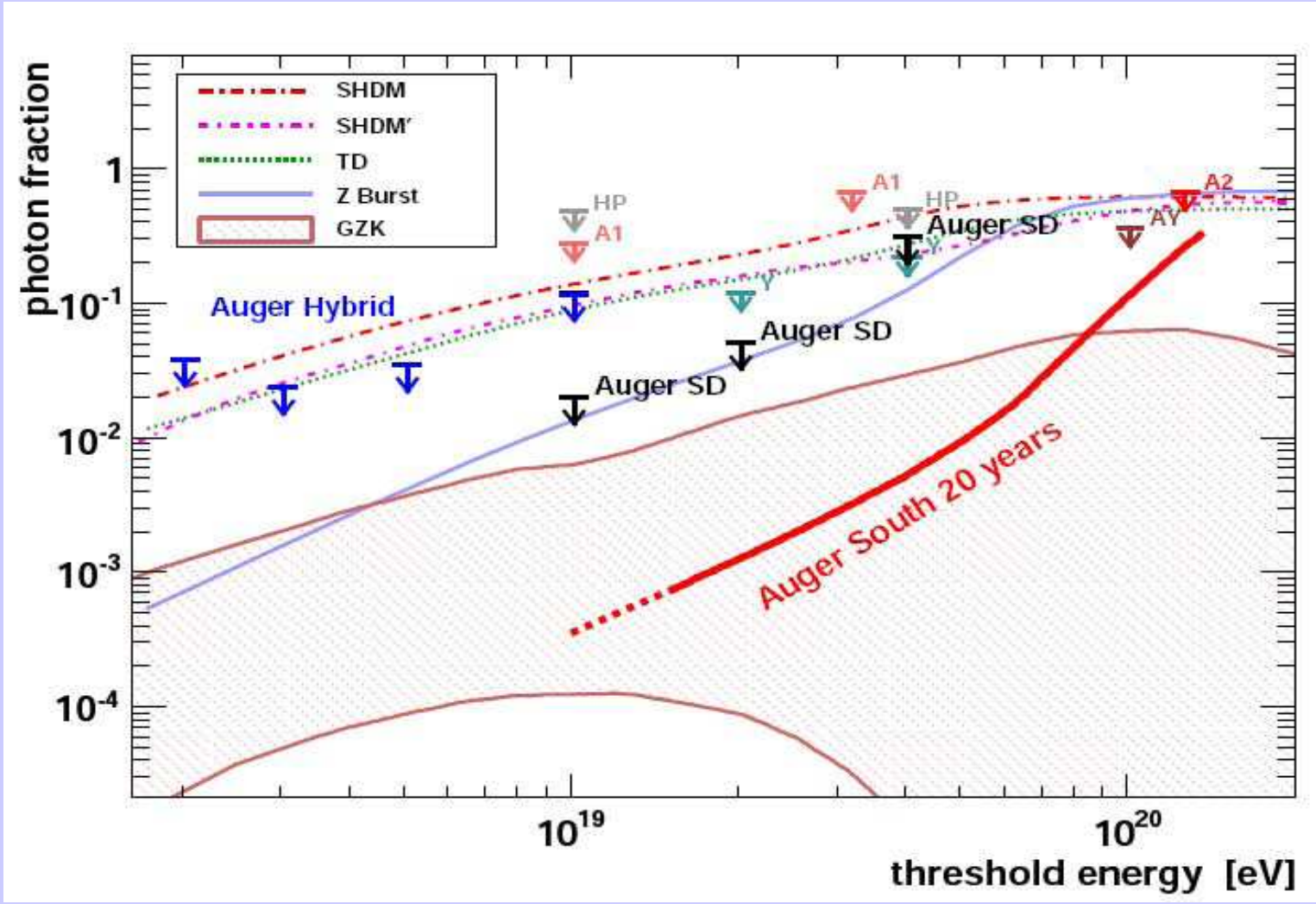
Consistent with fluctuation of hadronic background

Particles Type

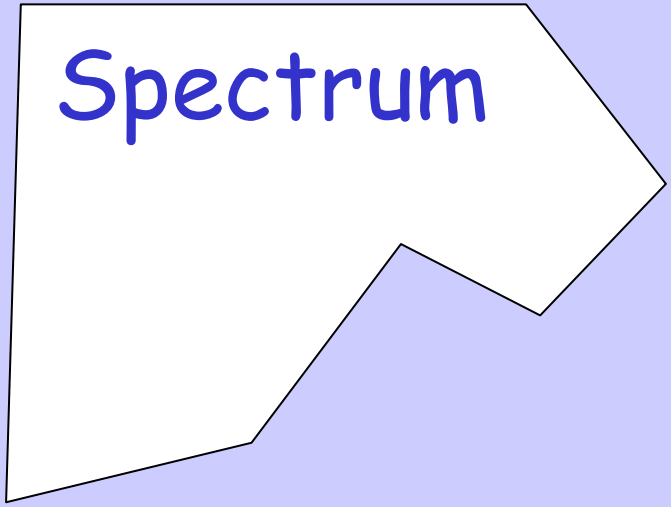


Top Top-down models severely constrained!
The FD FD-hybrid limit complements the array results and extends to lower energies

Particles Type

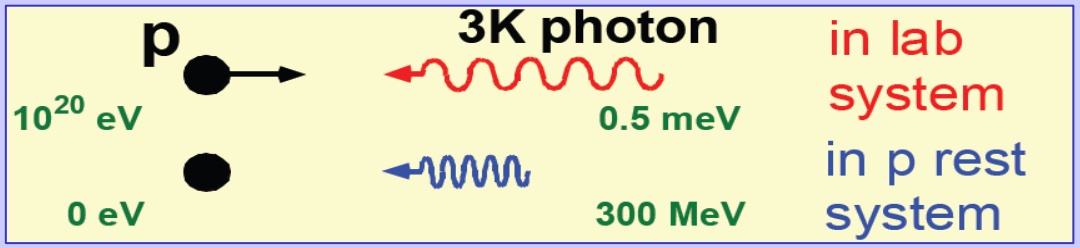


The extended site in the Northern Hemisphere would help (~factor7)

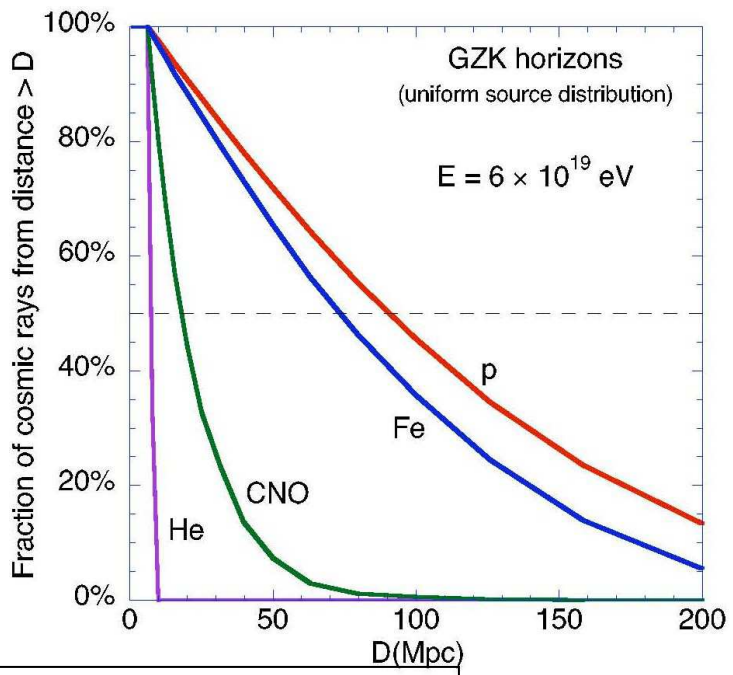

Spectrum

The Greisen Zatsepin Kuzmin prediction

Protons interact with CMB



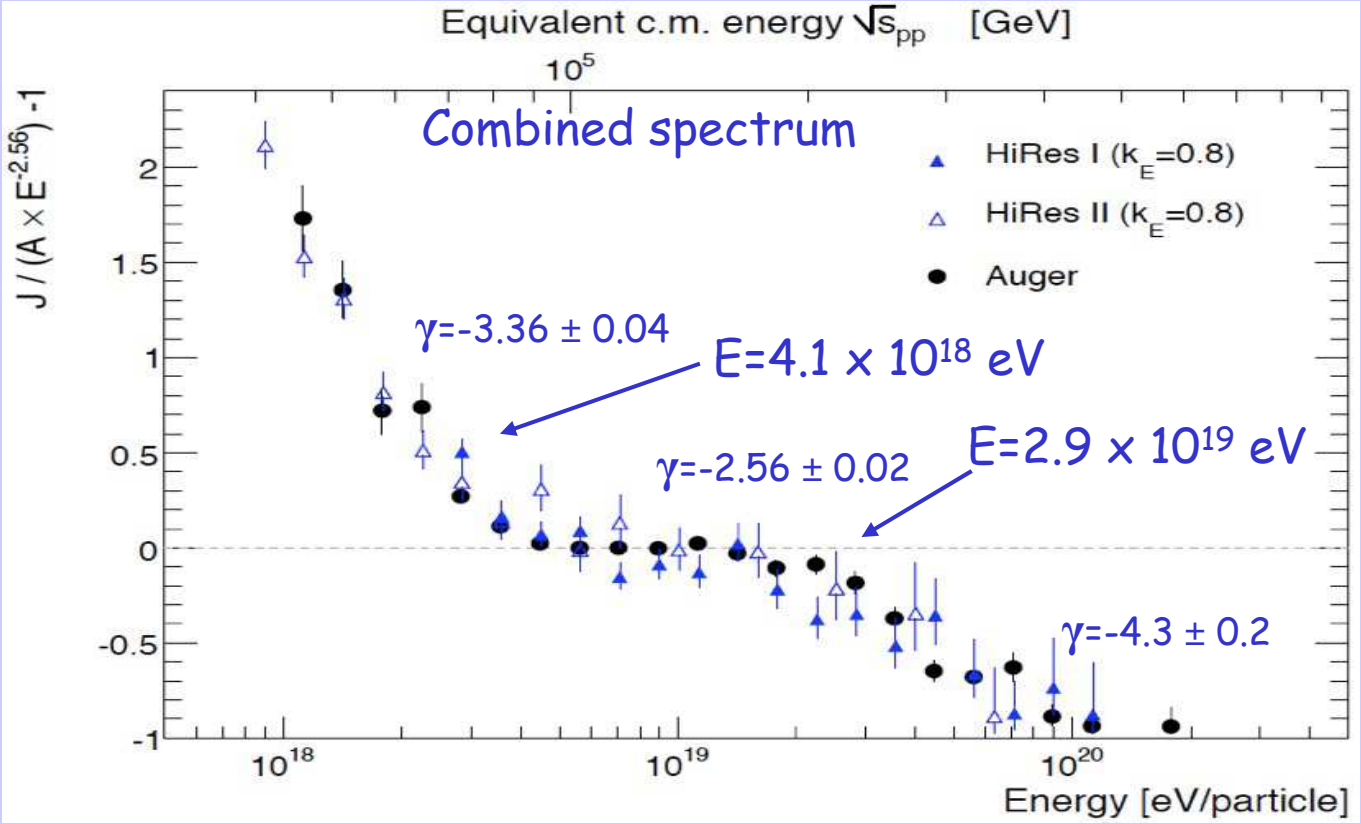
Photon dissociation for heavier primary



The Universe is opaque for E > 6 x 10^{19} eV

If Cosmic Rays are protons AND
power-law spectrum at the source > 10^{20} eV AND
sources are universally distributed
Then a depression of the flux is expected for E> 6 x 10^{19} eV

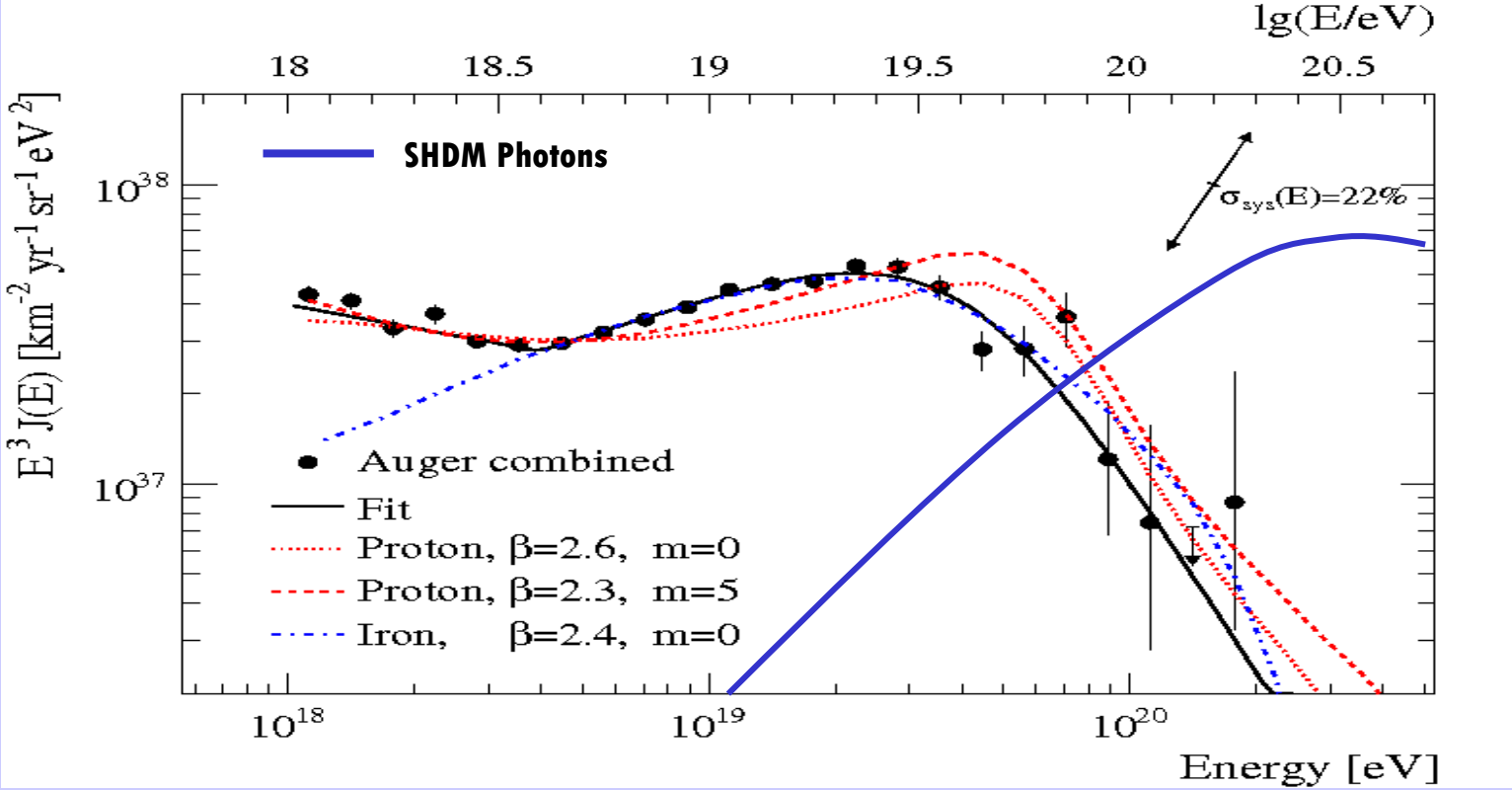
The Spectrum



The ankle is about in the expected place.
A steepening is found at energy of about 2.9 x 10^{19} eV

Probably the AUGER steepening means that the CRs are protons

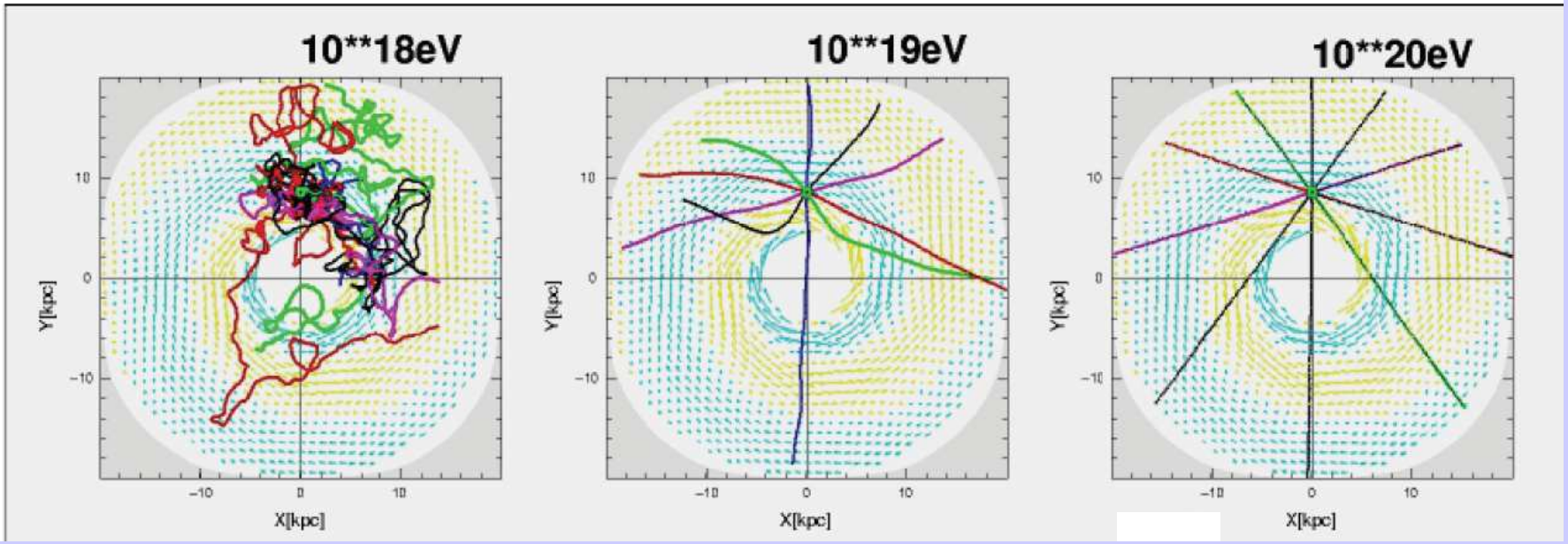
The Spectrum



The measured spectrum is well in agreement with a GZK hypothesis.
SHDM subdominant scenario is severely constrained

Arrival Direction

Highest-energy particles must be extragalactic



Deflection < 1°

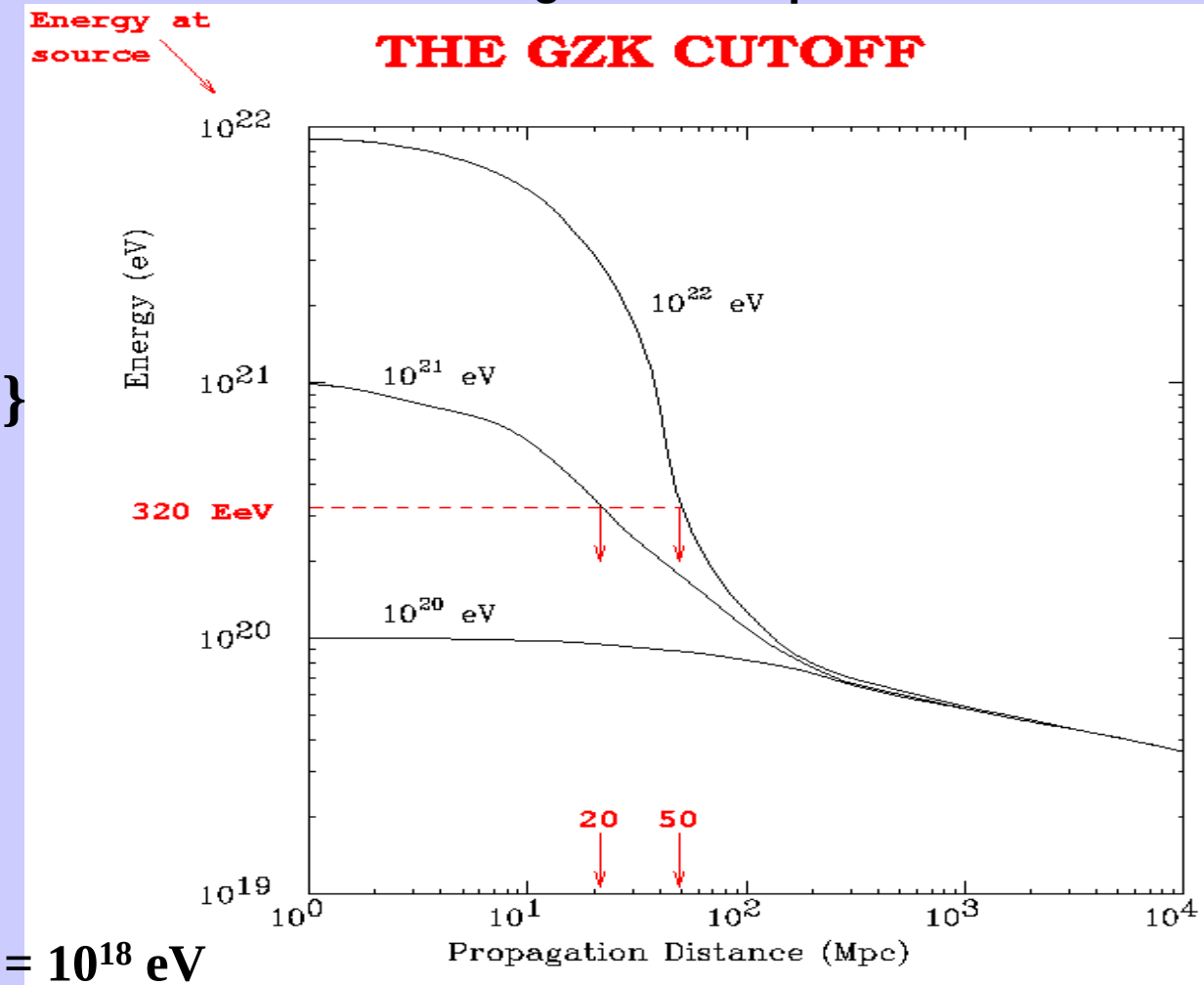
Arrival Direction

Above E ≈ 5*10^{19} eV, protons loose rapidly energy via pion photoproduction.
Energy loss ≈ 15 % / interaction. Interaction length ≈ 10 Mpc

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

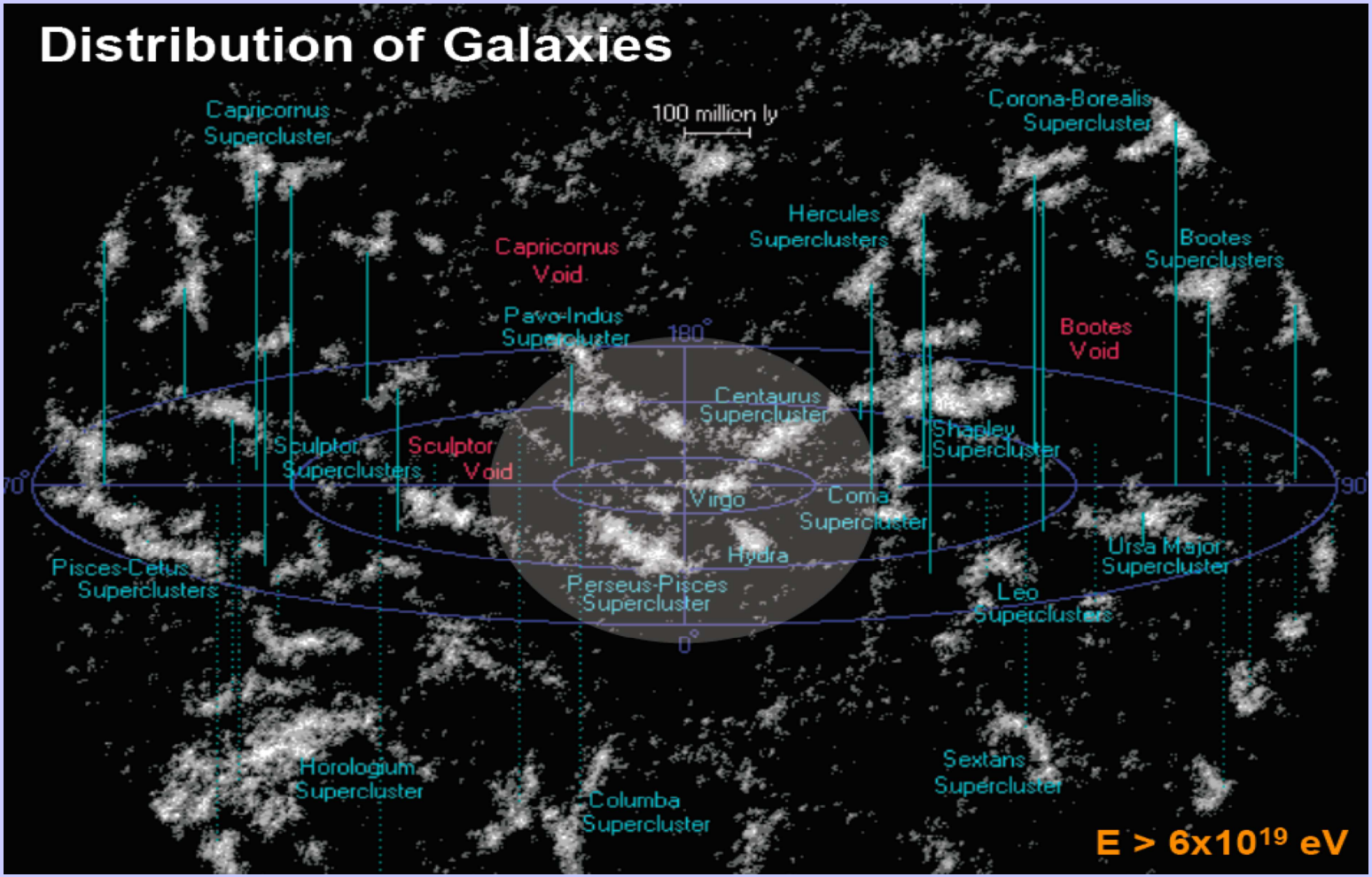
$\{\gamma$ **from** π^0 , ν **from** $\pi^+\}$

GZK Horizon



1 pc = 3.26 light year **1 EeV = 10^{18} eV**

Arrival Direction



If UHECR are protons then they direction distribution must be anisotropy
The higher energy Cosmic Rays can open a new window for astronomy

Arrival Direction

Data Set

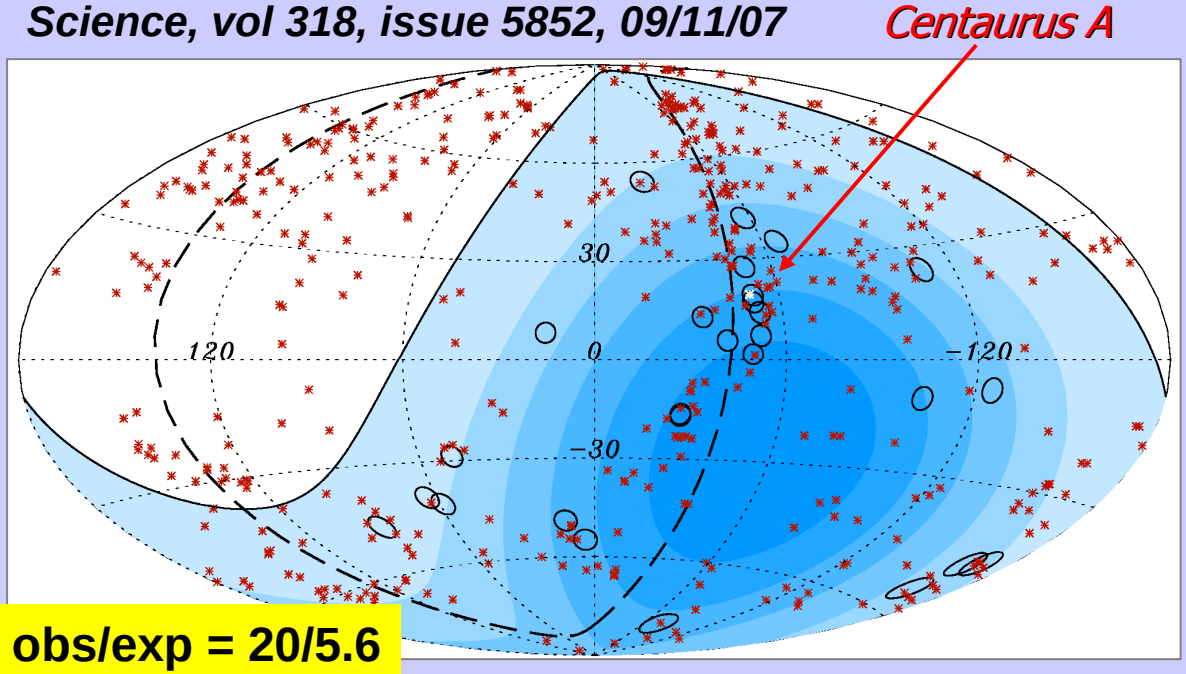
01/01/2004 – 31/08/2007

27 events

E>57 EeV
Angular bin 3.1°
D_{max}=75 Mpc

20 events are correlated with a AGN

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



obs/exp = 20/5.6

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

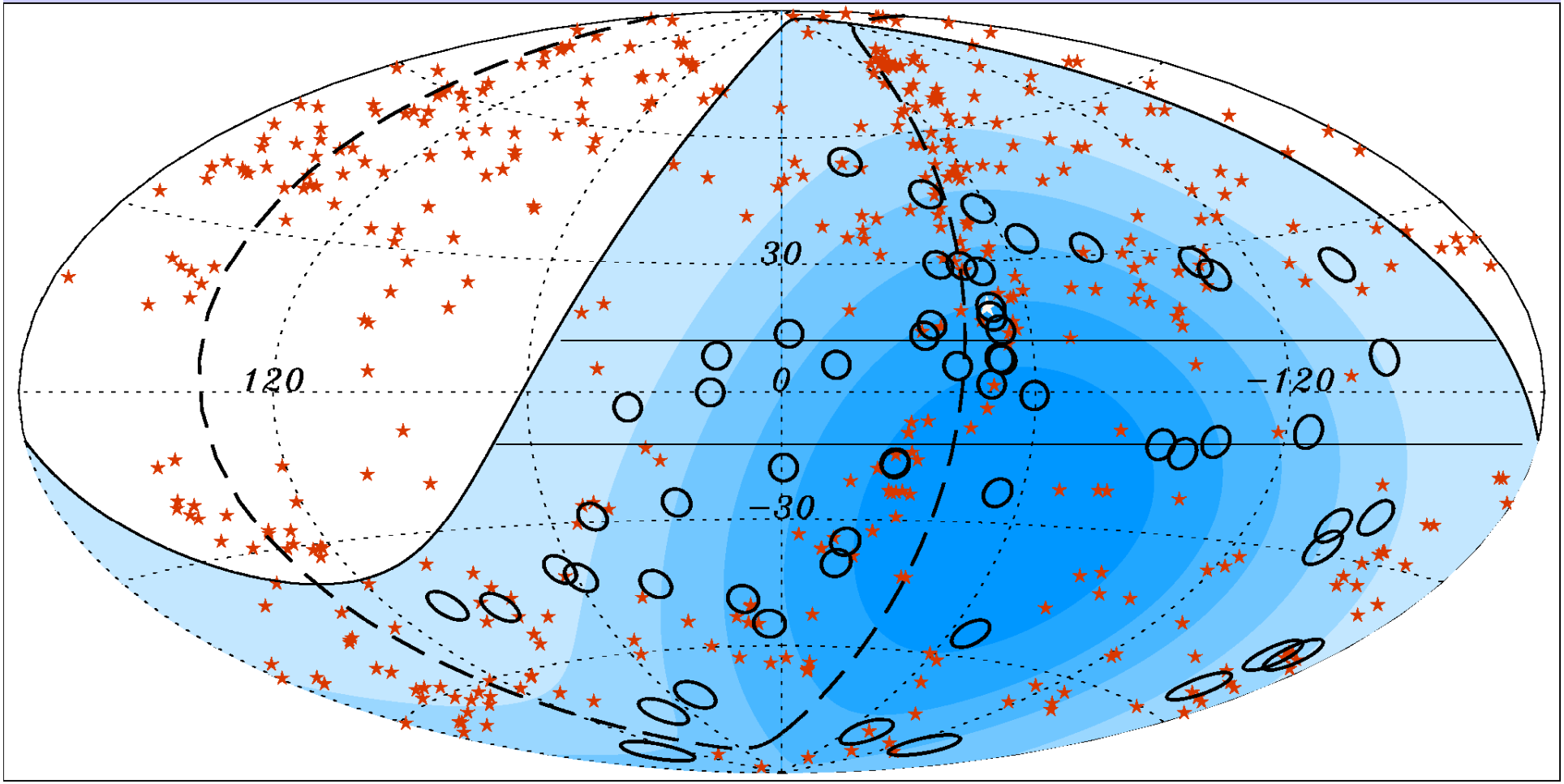
× *472 AGN with D<75Mpc (318 in the FOV of Auger)*
(catalogue Veron-Cetty and Veron)

The probability for an isotropy distribution is $P\sim10^{-5}$

Consistent with the Protons Hypothesis

Arrival Direction

Region of the sky with galactic latitude $|b| < 12^0$ is also indicated

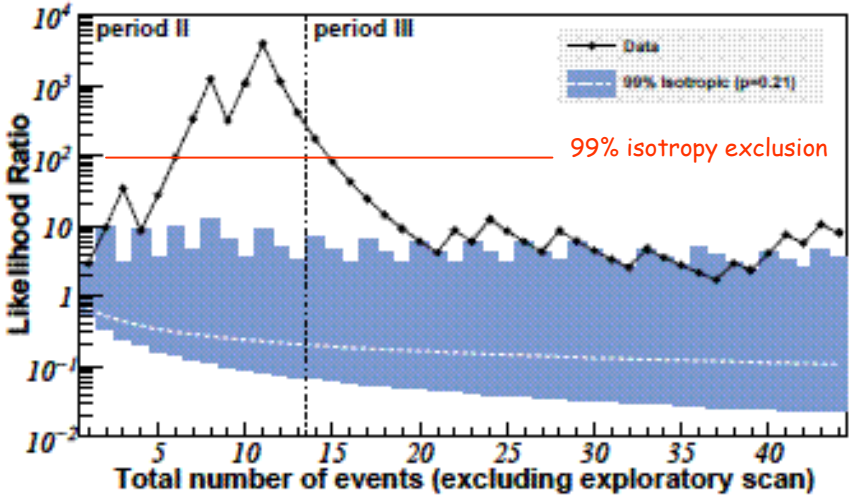


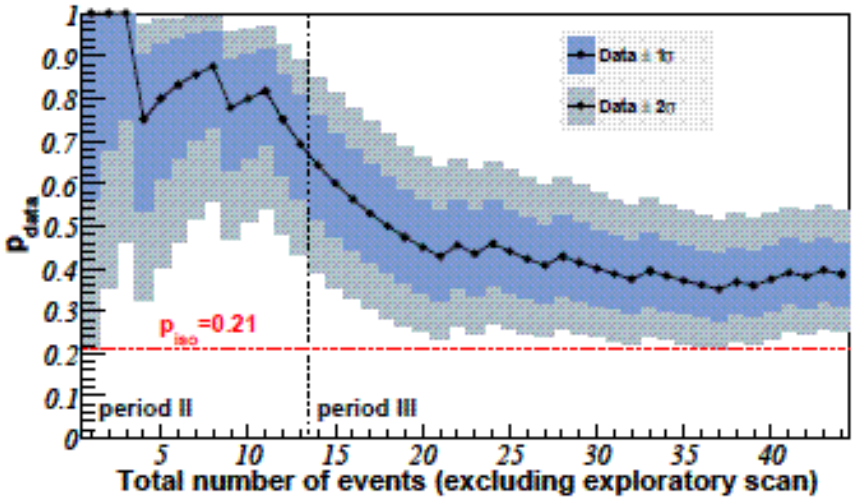
Arrival Direction

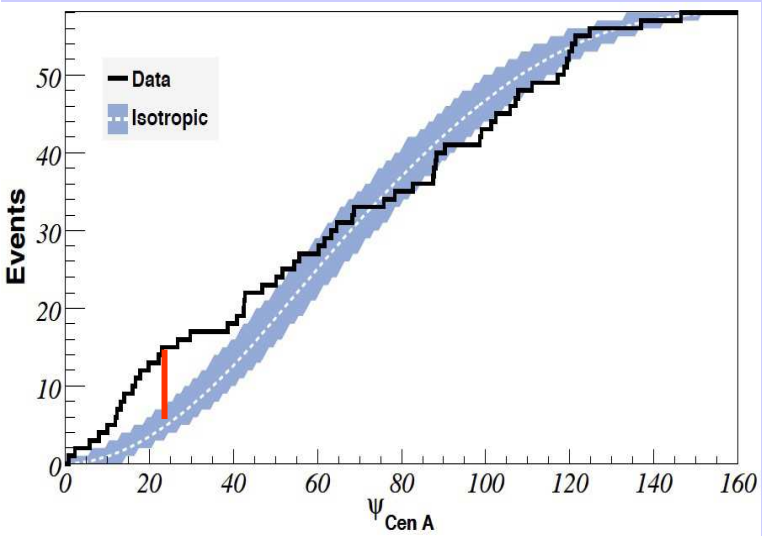
	Number of events E > 55 EeV	Correlated with AGN ψ = 3.1 degree	Expected for isotropy
Data August 2007 (Science paper)	27	18	5.7
Excluding band on galactic plane (|b| > 12 degree)	21	17	5.3
Data March 2009	58	26	12.2
Excluding band on galactic plane (|b| > 12 degree)	45	25	11.3

Probability of isotropic distribution: 6×10^{-3} (2×10^{-3})

Arrival Direction





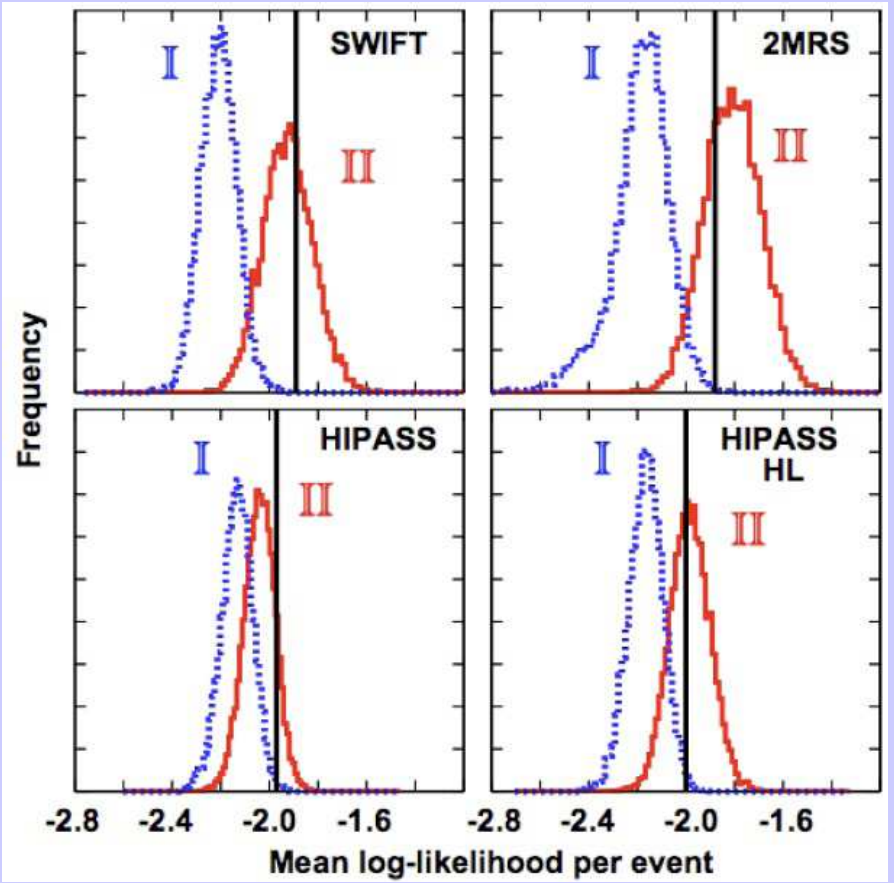


17/44 post scan events correlate still preferred an anisotropic distribution

Assuming only CenA as CRs detectable source 2% chance probability for isotropic distribution

Arrival Direction

Other catalogues are used
Swift-BAT
uniform, hard X-ray
261 Seyfert galaxies
2MRS vol selected
1940 brightest from
2MASS cat.
HIPASS
3058 H1 galaxies
HIPASS HL
759 high luminosity



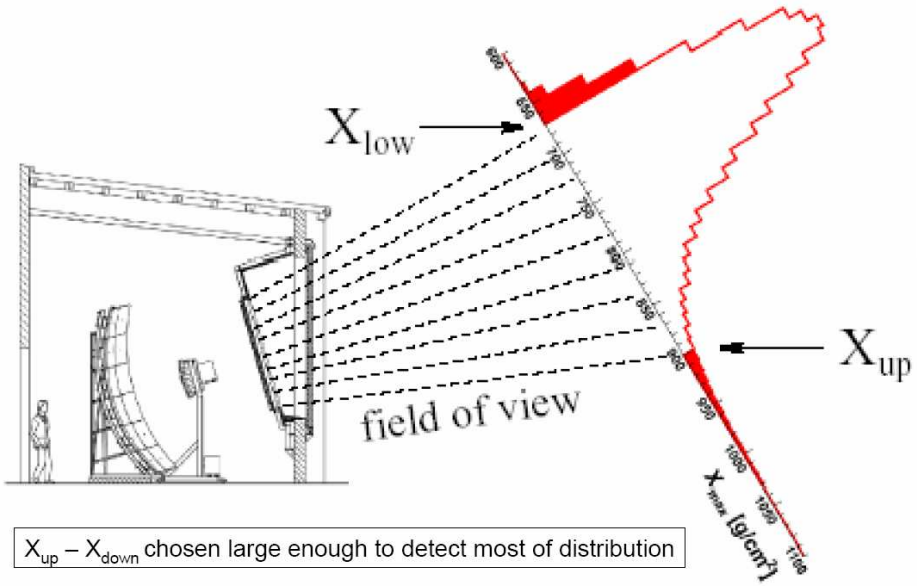
If we believe in anisotropy of UHECRs then they can be protons

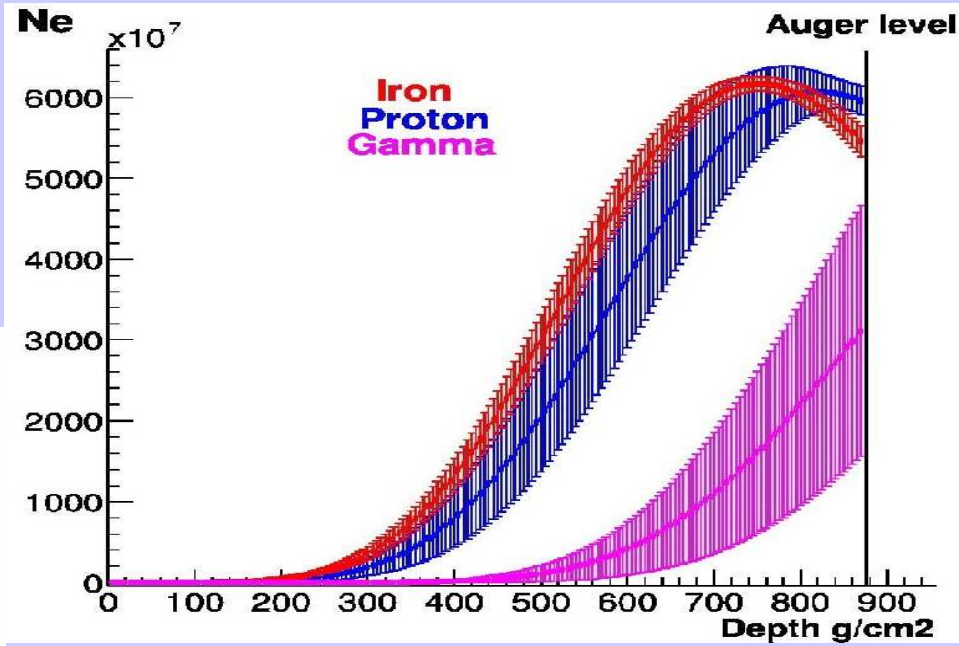

Mass Composition

Mass Composition

AUGER is a hybrid detector!

Using the FD detector we can measure the X_{max} of the shower

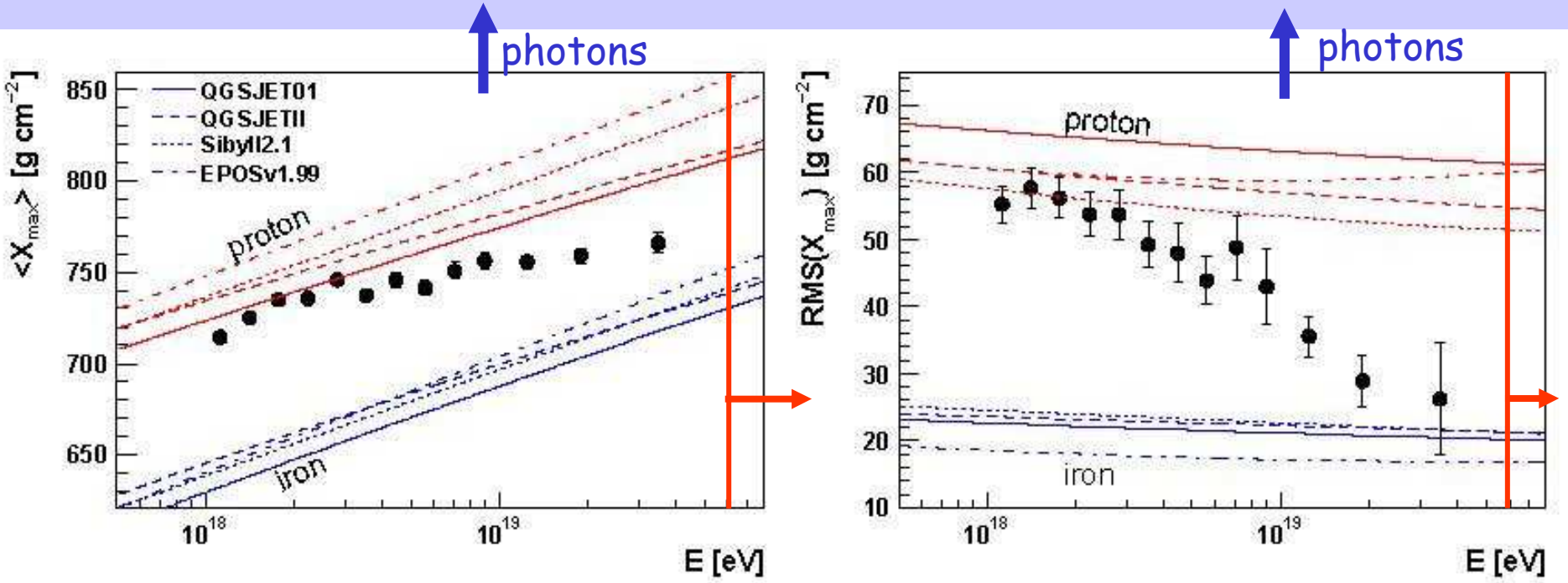




Showers induced by different primary develop in a different way in the atmosphere.
Protons interact deeper of iron and the RMS of the X_{max} is norrow

Mass Composition

Hybrid duty cycle 10% of SD. Not enough statistics in the more interesting energy range !



Start energy for anisotropy analysis

But hybrid analysis indicate that mass composition turns heavy

UHECRs scenario

AUGER South is complete and is taking data:

- event sample (>10^{19} eV) larger than sum of all previous experiments,
- AUGER energy and angular resolution better of previous experiments
- AUGER statistics is growing fast

Contamination of not charged particles negligible

- Upper limit in photon flux already exclude top-down models
- No neutrino like candidate found

Spectrum

- consistent with a GZK-like cut-off (E=2.9 x 10^{19} eV)
- ankle seen at E=4.1 x 10^{18} eV (galactic to extra-galactic transaction?)
- GZK cut-off hints a proton hypohesis for E>55 EeV

Arrival Direction

- still data prefer an anisotropy scenario at highest energy (>55 EeV)
- possible extra-galactic origin inside the GZK cut-off
- the anisotropy hints a proton hypotesis for E>55 EeV

Mass Composition

- the only analysis strongly model dependent
- comparison with Monte Carlo essential
- indicate a mixed/heavy composition but for E<55 EeV

UHECRs scenario