

Recent results from the Pierre Auger Observatory

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Rencontres de Moriond EW, March 13-20 2011

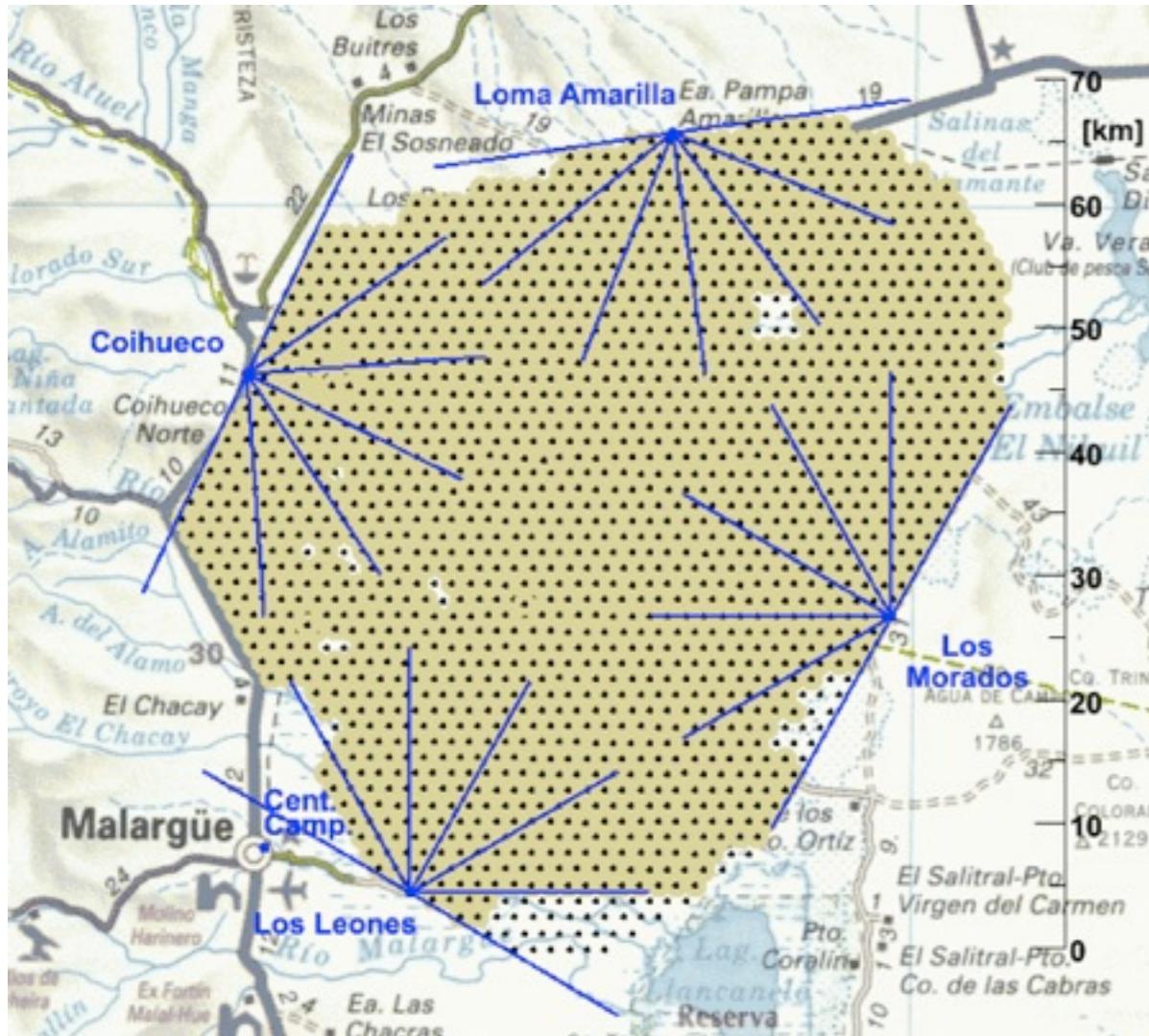
Outline

The Pierre Auger Observatory
Goal, Brief description, philosophy

Results, towards the understanding of UHECR's
Spectrum
Anisotropy
Mass composition , Shower physics

Summary

The Pierre Auger Observatory in Argentina



Surface detectors
1680 Cherenkov stations
1.5 Km spaced on a hexagonal grid



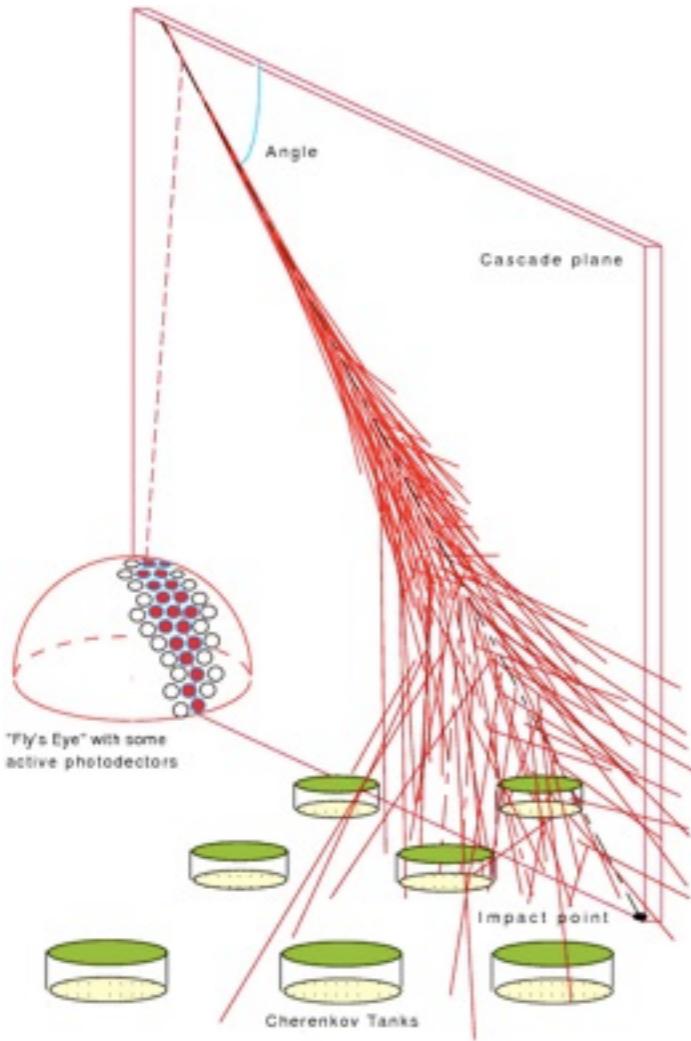
Fluorescence detectors
4 building with 6 telescopes each
Telescope f.o.v. 30 x 30



Completed in 2008
Progressive data taking starting in 2004

Aiming at understanding the origin of Ultra High Energy Cosmic Rays,
the PAO associates the widest detection surface (3000 km^2)
together with the highest precision ever achieved

The Auger Hybrid concept: more than 2 detectors !



SD provides:

- Huge aperture (100% duty cycle) easily calculable
- Robust detectors
- Good angular resolution
- Promising Mass composition indicators

FD provides:

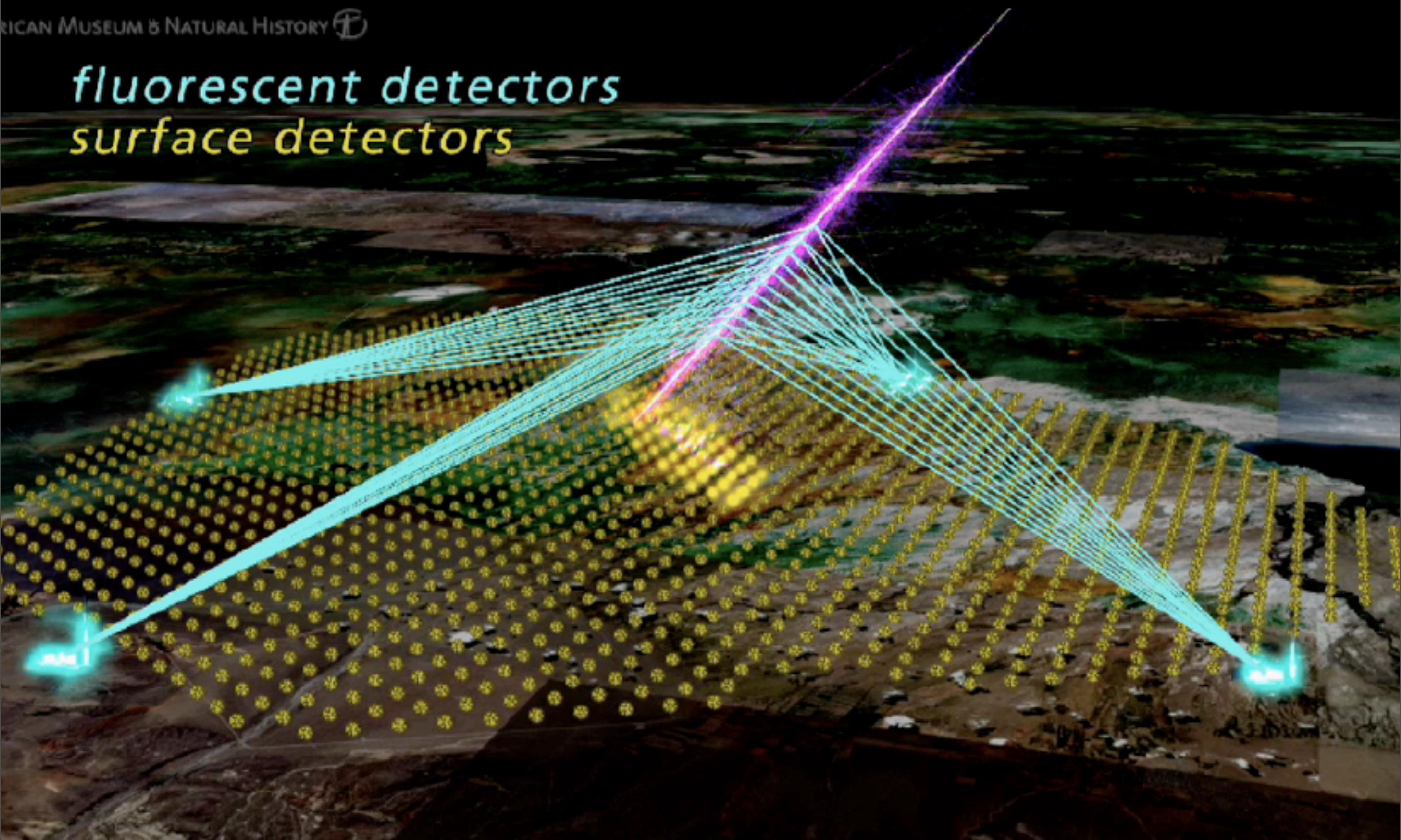
- Fluorescence light emitted in proportion to energy deposit: -> Near calorimetric energy measurements
- A direct view of shower maximum (composition)
- Precise directions (hybrid method).
- But duty cycle is only 10-15%

Where possible, minimise use of simulations in the production of key scientific outputs
– e.g. SD energy spectrum, composition (~ minimal use)

Take advantage of Auger's hybrid nature.

- FD calibrates SD energy scale
- hybrid directions cross-check SD directions
- other SD cross-checks like exposure FD/SD

*fluorescent detectors
surface detectors*

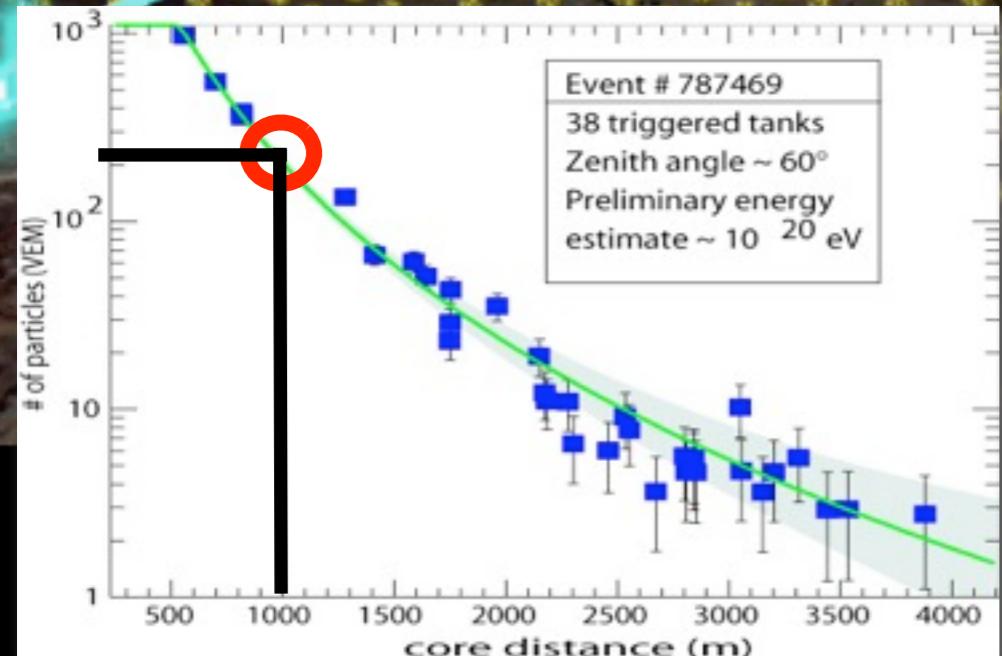


Energy measurement

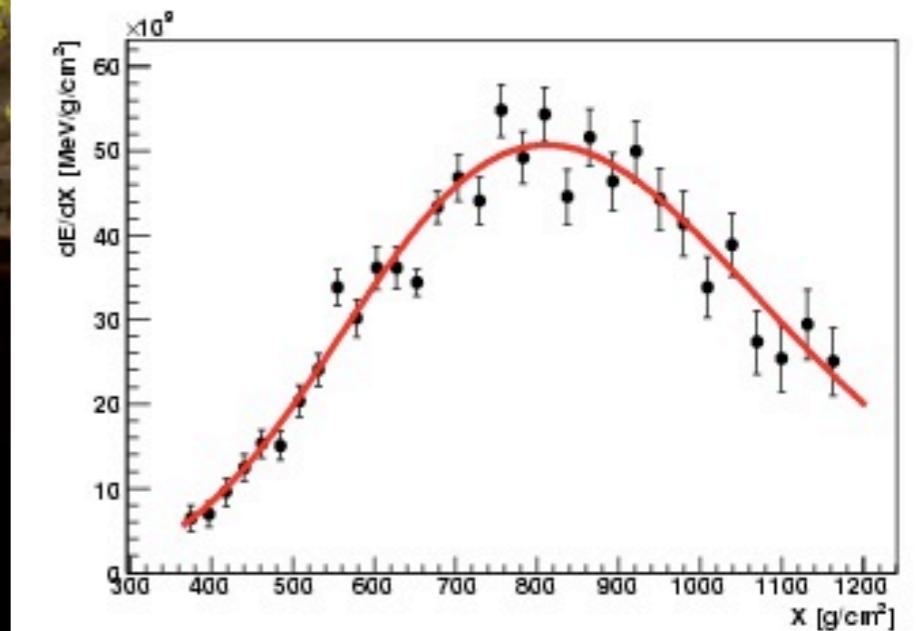
N MUSEUM & NATURAL HISTORY

*fluorescent detectors
surface detectors*

SD energy parameter S(1000)
from lateral profile



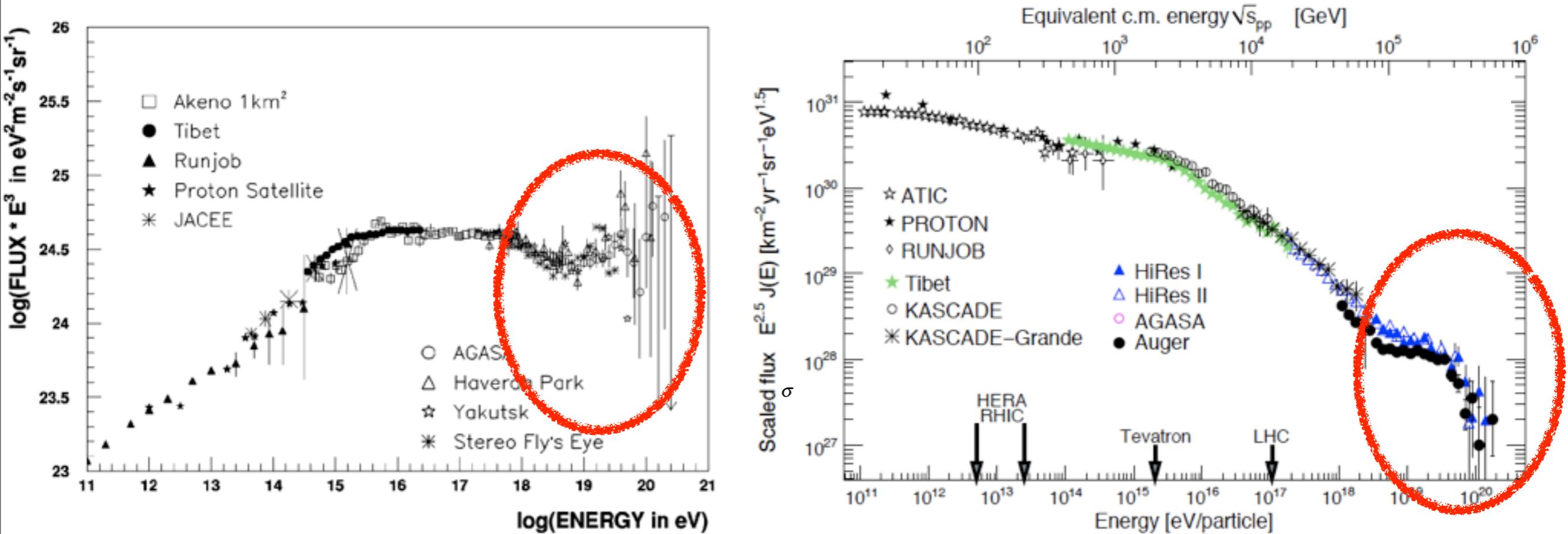
FD energy
from longitudinal profile



PROGRESS:
Calibration of SD energy
estimator through FD

Spectrum

Energy spectrum before and after Auger



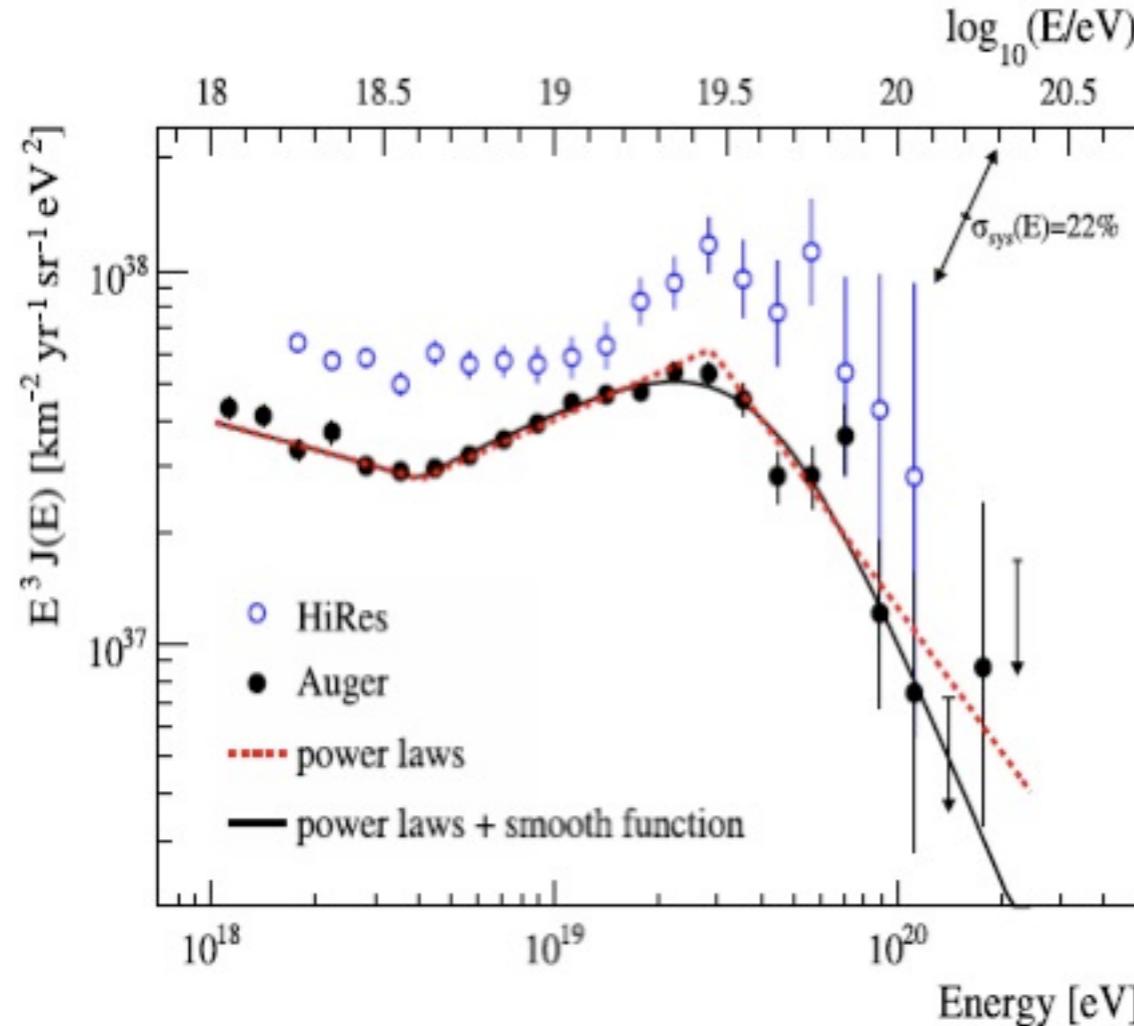
The spectrum measurement has improved a lot in 10 years !

- Sharp ankle at ~4 EeV
- Clear suppression of the flux above ~50 EeV (HiRes, Auger)

flux drop to 50% at $\log E = 19.6$, significance $\sim 20\sigma$.

Consistent with GZK suppression.

Combined Energy Spectrum (SD and hybrid)



Parameter	Power Laws	Power Laws + smooth function
$\gamma_1(E < E_{\text{ankle}})$	3.26 ± 0.04	3.26 ± 0.04
$\log_{10}(E_{\text{ankle}}/\text{eV})$	18.61 ± 0.01	18.60 ± 0.01
$\gamma_2(E < E_{\text{break}})$	2.59 ± 0.02	2.55 ± 0.04
$\log_{10}(E_{\text{break}}/\text{eV})$	19.46 ± 0.03	
$\gamma_3(E > E_{\text{break}})$	4.3 ± 0.2	
$\log_{10}(E_{1/2}/\text{eV})$		19.61 ± 0.03
$\log_{10}(W_c/\text{eV})$		0.16 ± 0.03
χ^2/ndof	$38.5/16$	$29.1/16$

Pierre Auger Collaboration / Physics Letters B 685 (2010) 239–246

Auger and HiRes spectra consistent within systematic errors (22% and 17% respectively)

• Nature of suppression ?

Propagation : Energy loss in CMB(GZK) ? or
Acceleration: Injection spectrum .

• Ankle?

Transition Galactic/extragalactic ??

CR Composition needed to constraint models

Anisotropies

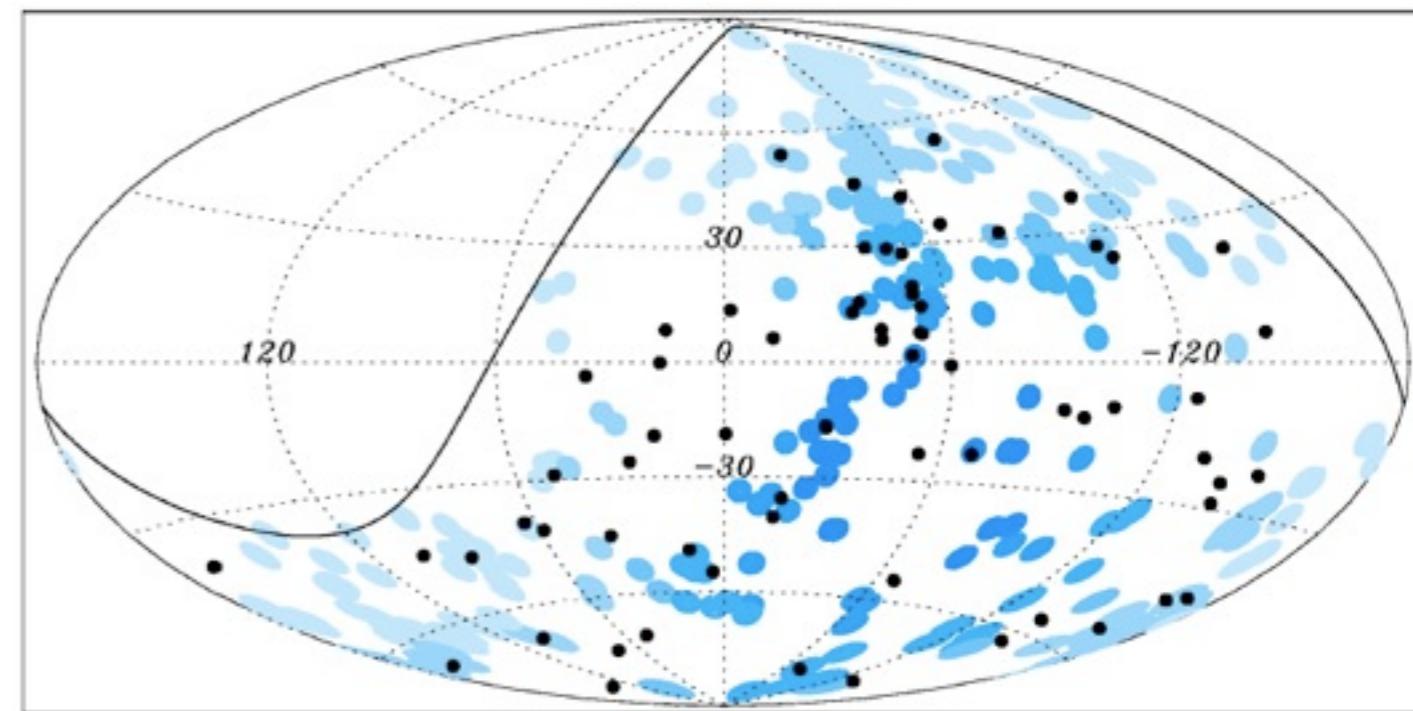
Anisotropies at UHE

Prescription: used early dataset to define energy cut, catalog and redshift cut, angle.
(12th VCV)

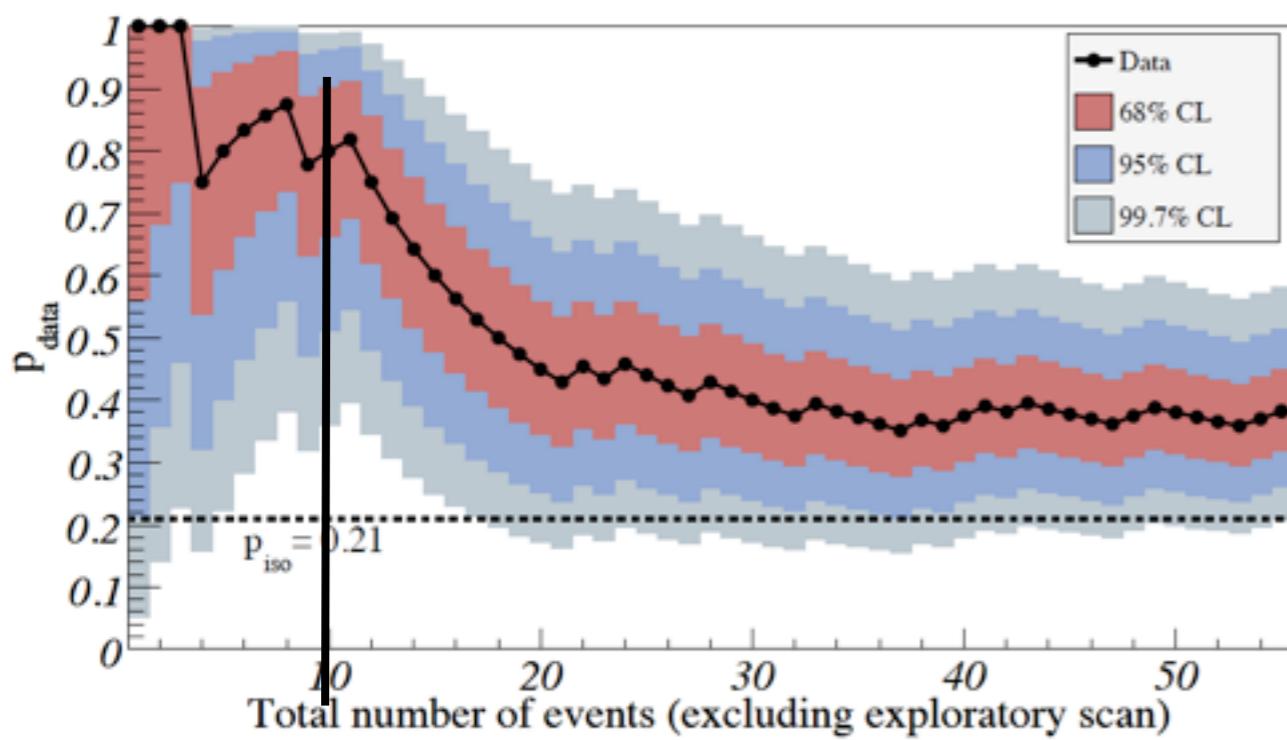
First published November 2007, *Science*

AGN correlation now weaker than first indicated, but is apparently still present (38 +/- 6 % compared with 21% for isotropy).

$E > 55\text{EeV}$, 3.1° , $z < 0.018$



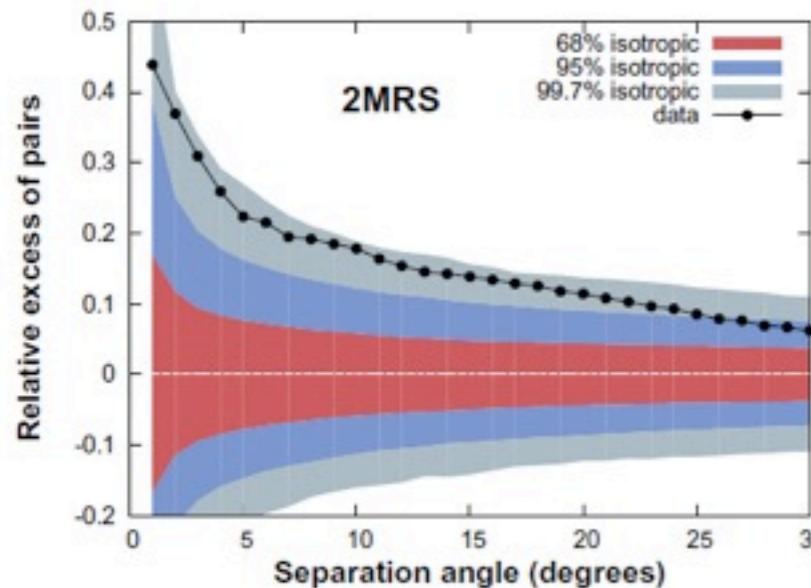
Degree of correlation $P_{\text{data}} = k/N$



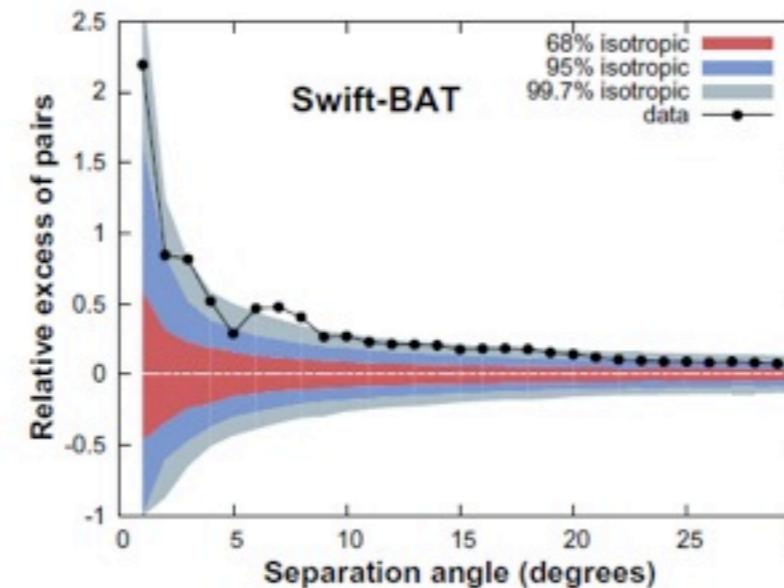
21/55 events now correlate
0.3% chance of finding this degree of correlation from an isotropic distribution

Search for correlations with other (more complete) catalogs of extra-galactic objects

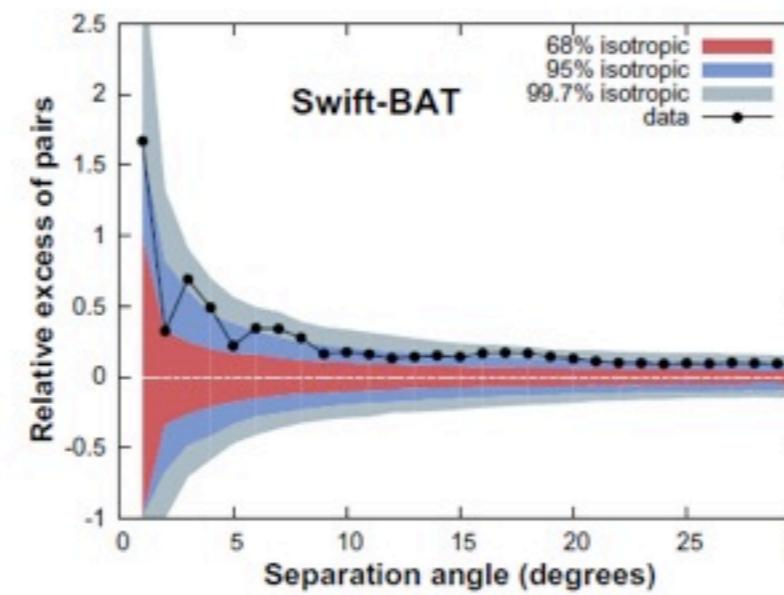
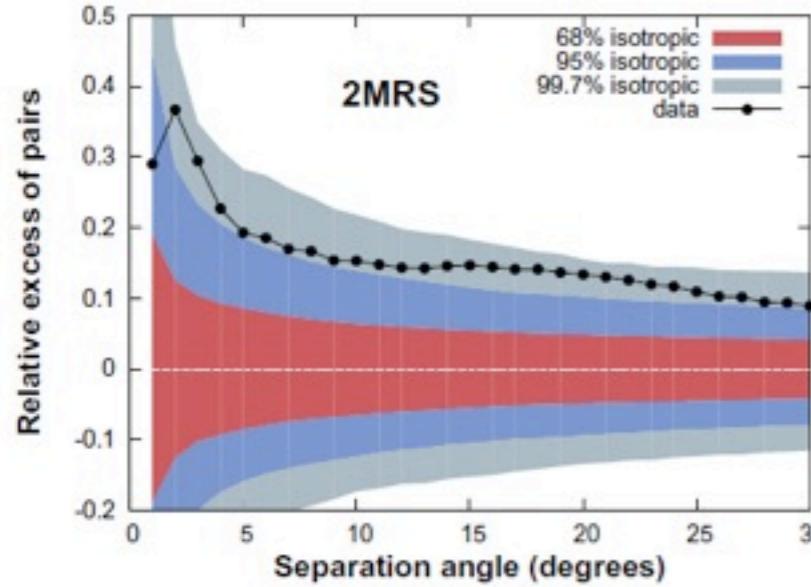
22,000 “normal” galaxies within 200Mpc



373 x-ray galaxies within 200Mpc



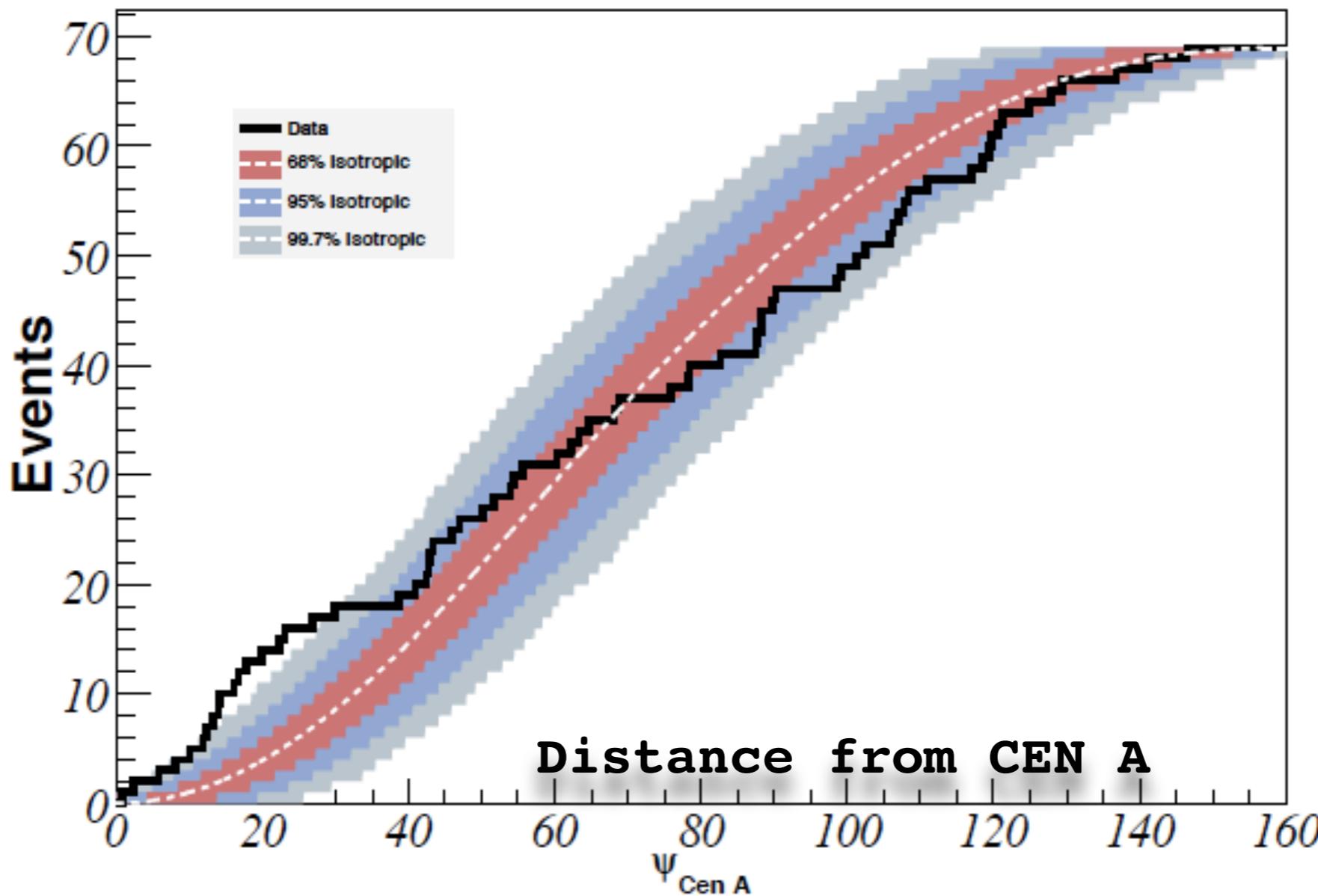
All events since 1/2004



Excluding early events
used to formulate AGN
prescription, particularly
the energy cut

- “a posteriori” analysis, but interesting
- 2 free parameters : deflection angle (magnetic field) and «isotropic fraction» (incompleteness, heavier elements, ...)
- excess of correlating pairs (event+catalog object) within separation angle above isotropic expectation 2MRS -> (1.5°, 64%); Swift -> (7.8°, 56%)

Auger: search for the largest excess (above 57 EeV):

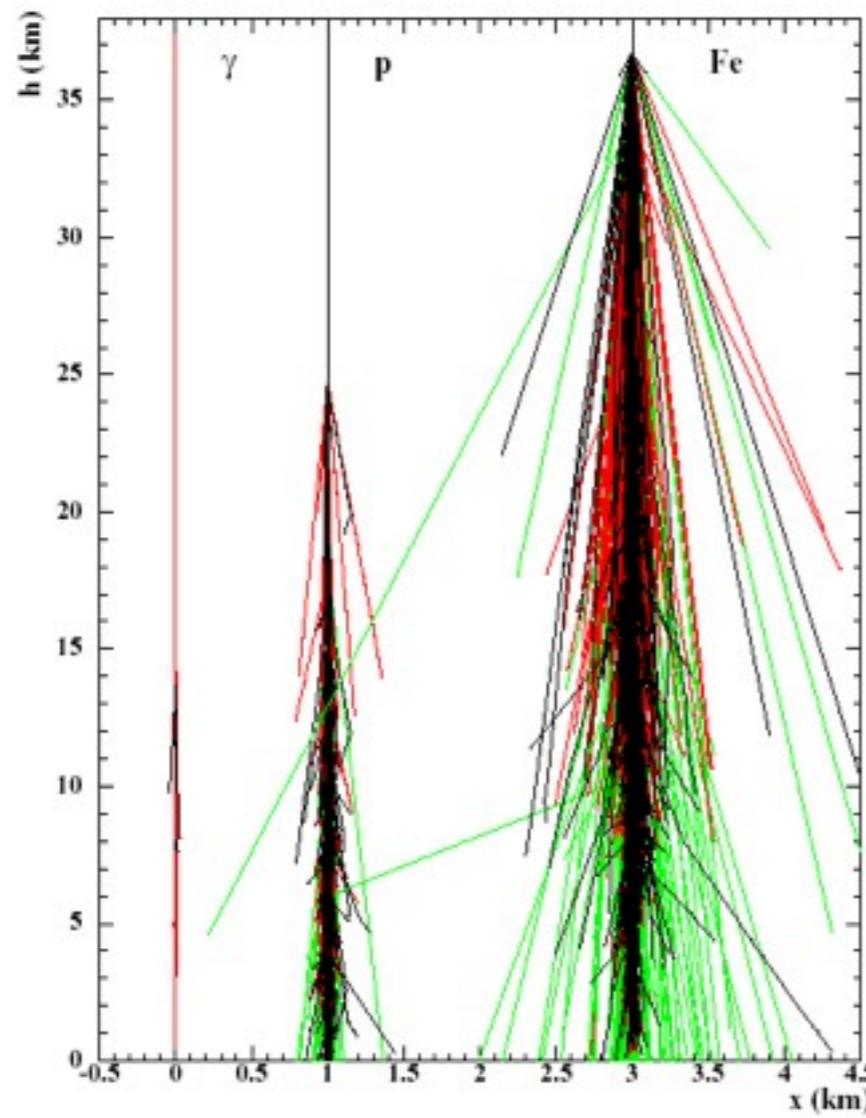


Centering on CEN A: largest excess within 18° (13 events vs 3.2 expected)

*Update on the correlation of the HECR with nearby extragalactic matter,
PA Collab., Astropart. Phys. 34 (2010) 314*

Mass composition

Composition from FD longitudinal profile

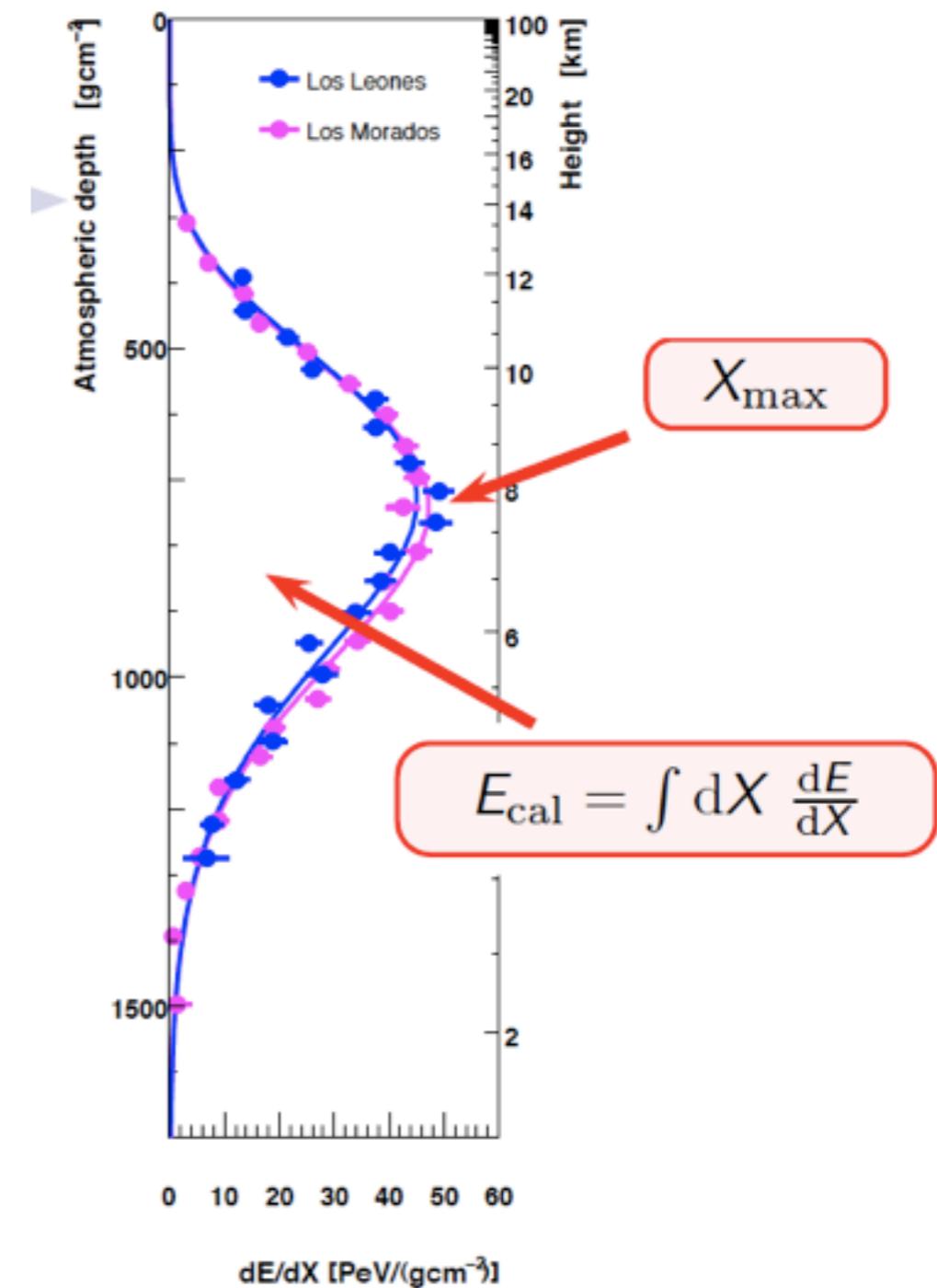


Fe shower develop higher in atmosphere
-> lower Xmax ($\sim 100 \text{ g.cm}^{-2}$ avrg)

Observables sensitive to composition:

- Depth of shower maximum ($\langle X_{\text{max}} \rangle$);
- Elongation rate ($d\langle X_{\text{max}} \rangle / d\log E$);
- RMS of X_{max} distribution at fixed energy:

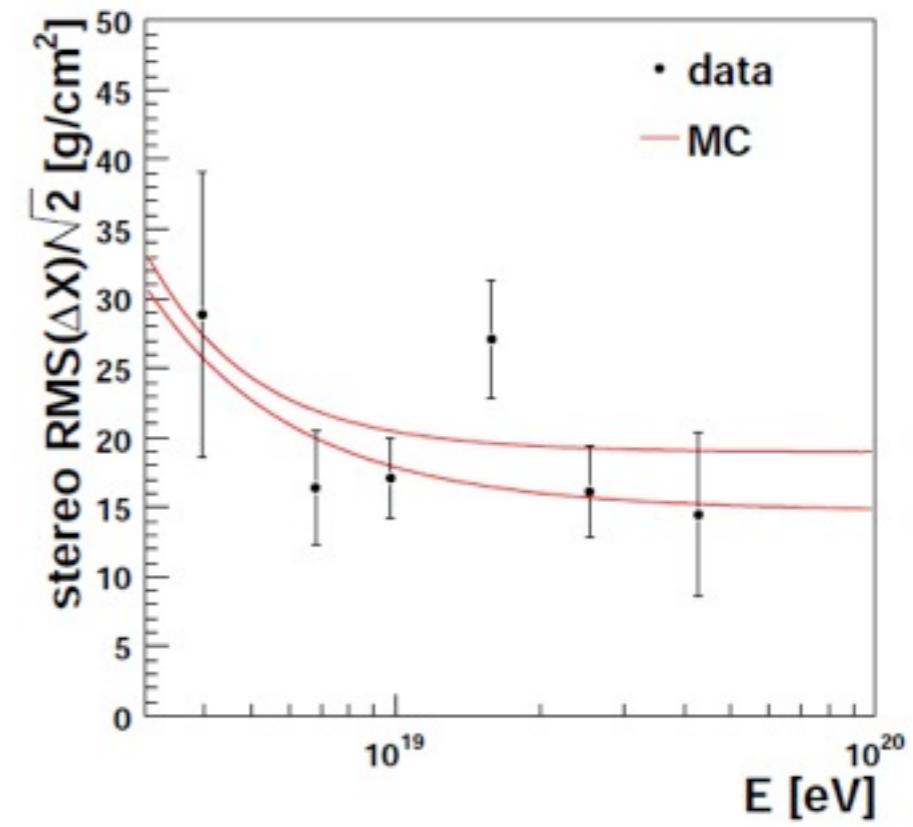
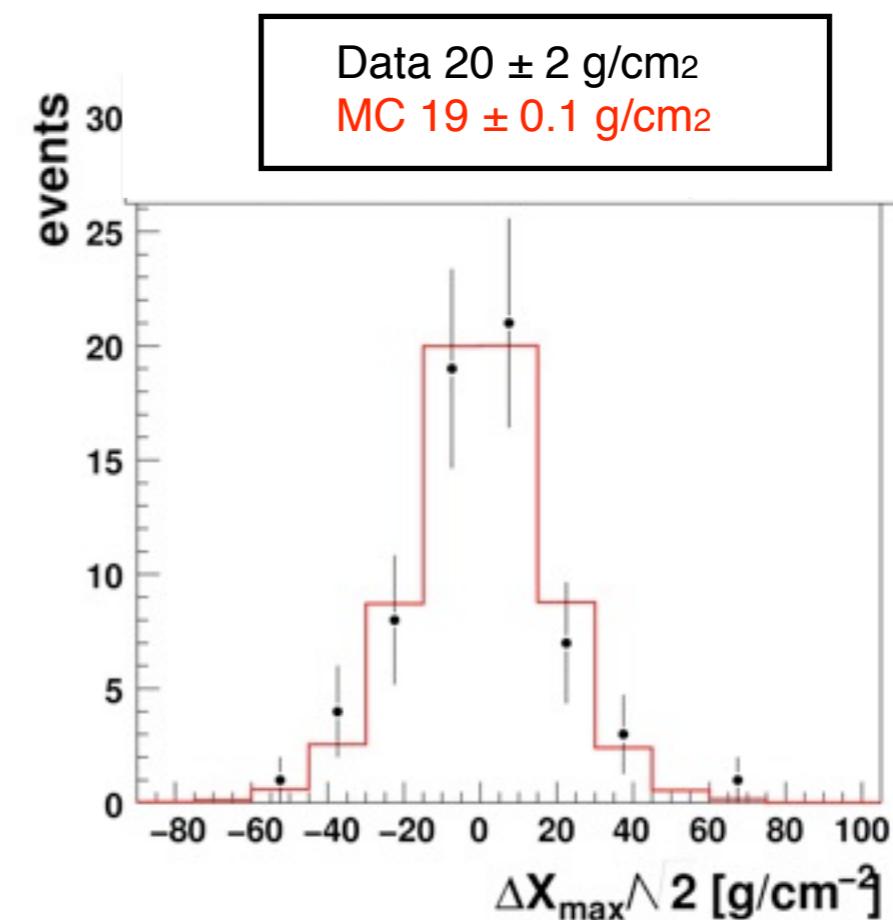
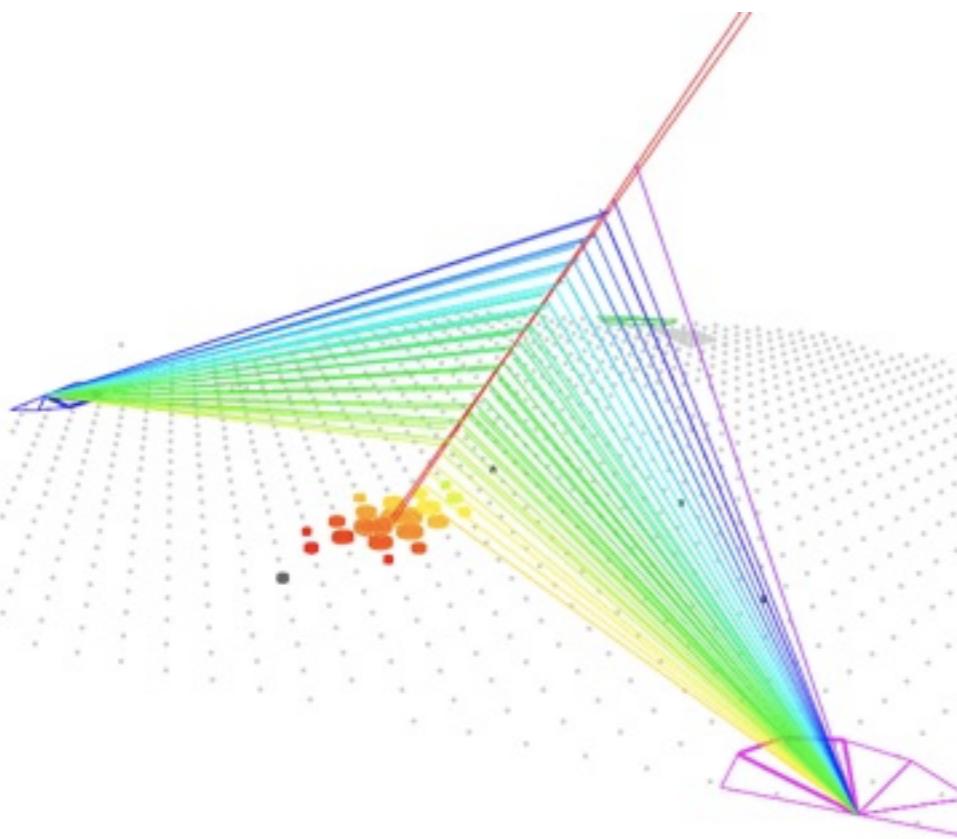
Cross check profiles
with stereo events



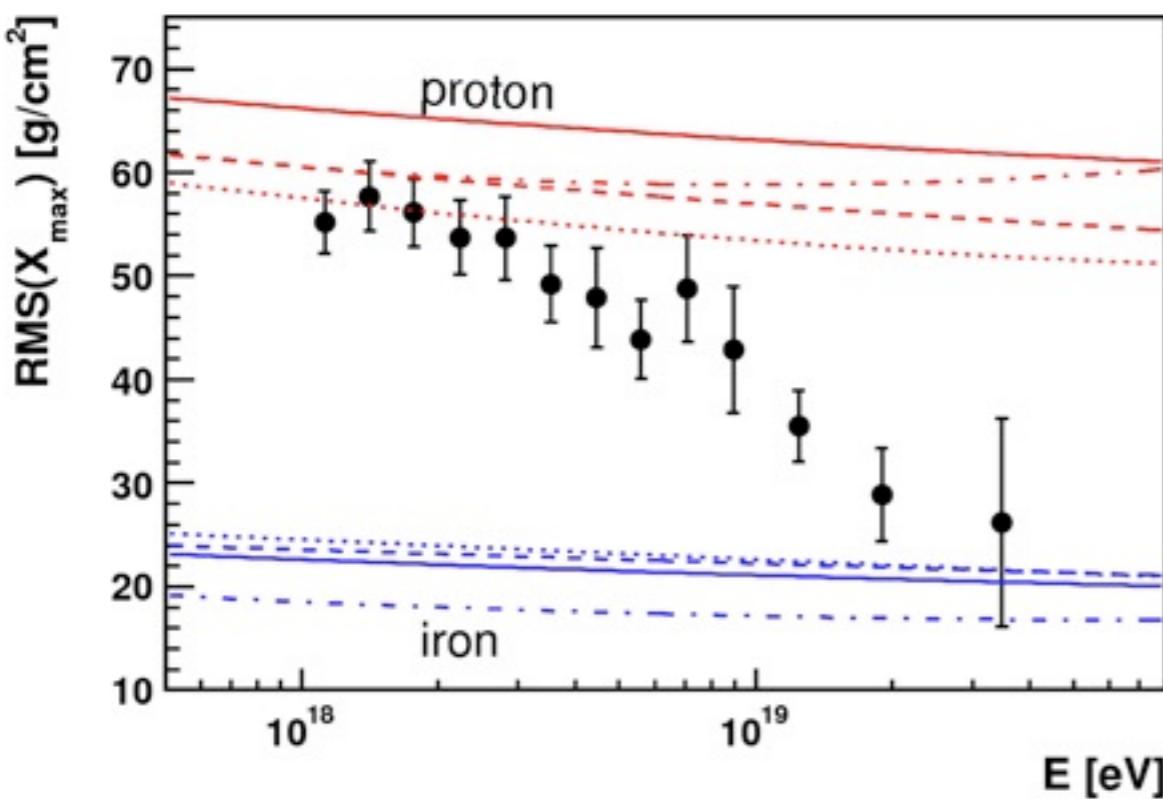
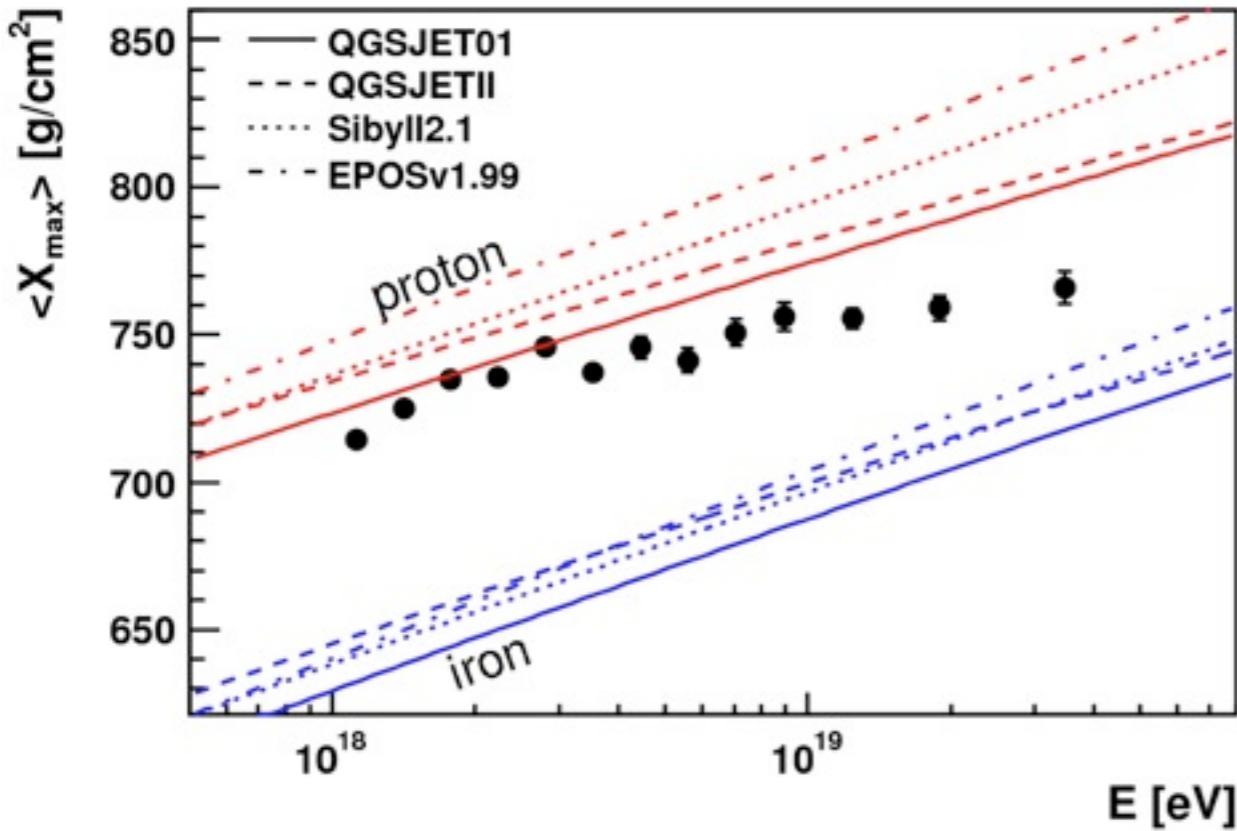
Resolution of the Reconstructed X_{\max}

The detector resolution of the reconstructed X_{\max} is estimated using MC simulations.

This resolution is validated by comparing X_{\max} measurements from two independent FD detectors.



Xmax Results



The data favor a break in the X_{\max} vs energy curve at :

$$E_b = 10^{18.25 \pm 0.05} \text{ eV}$$

an energy close to the ankle in the energy spectrum.

At energies above

$$E = 2 \times 10^{18} \text{ eV}$$

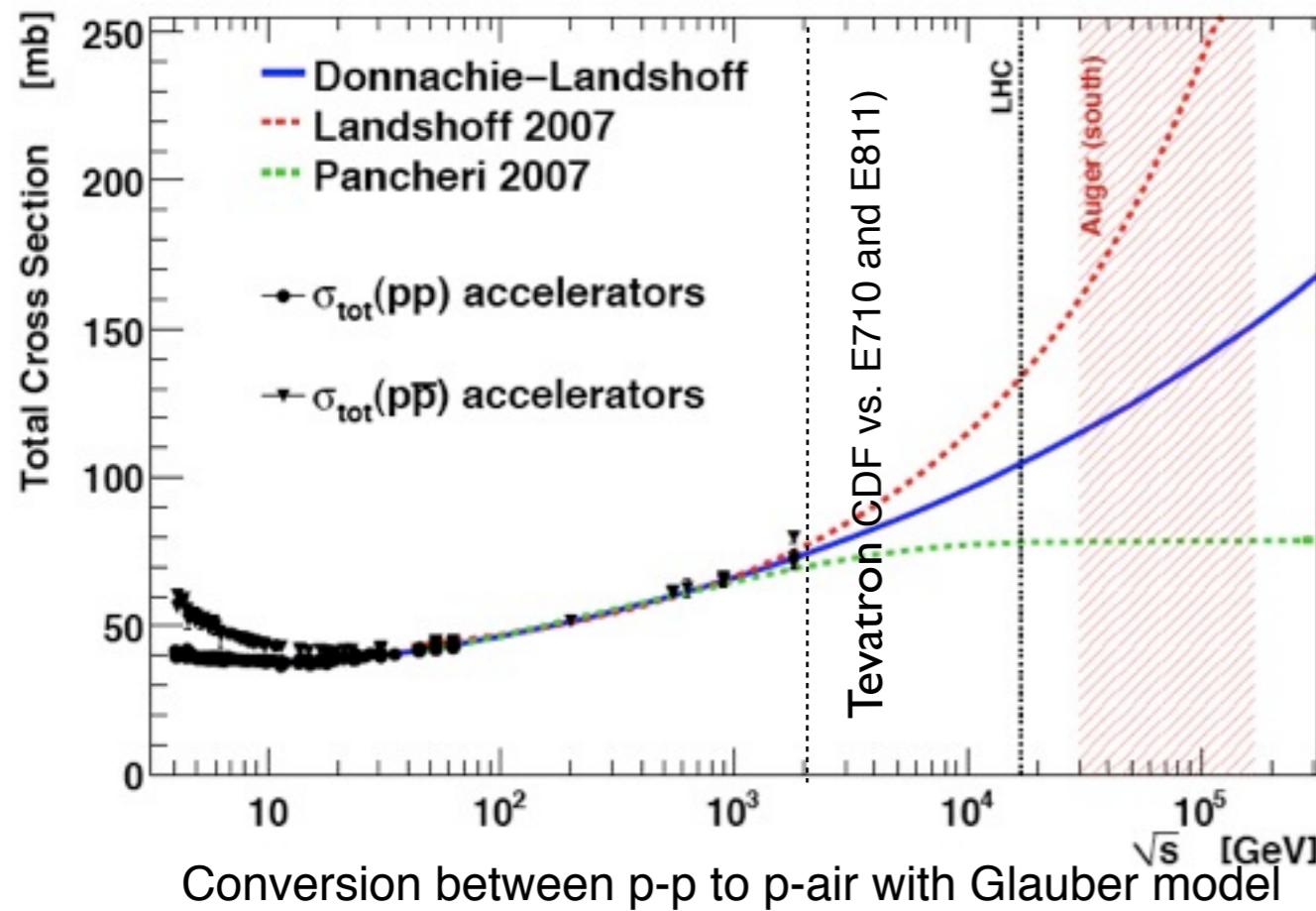
the small elongation rate, and the decreasing trend of the RMS(X_{\max}) suggest a composition change towards a heavier composition

Tension with anisotropies results?

Need statistics above 50 EeV (need SD)

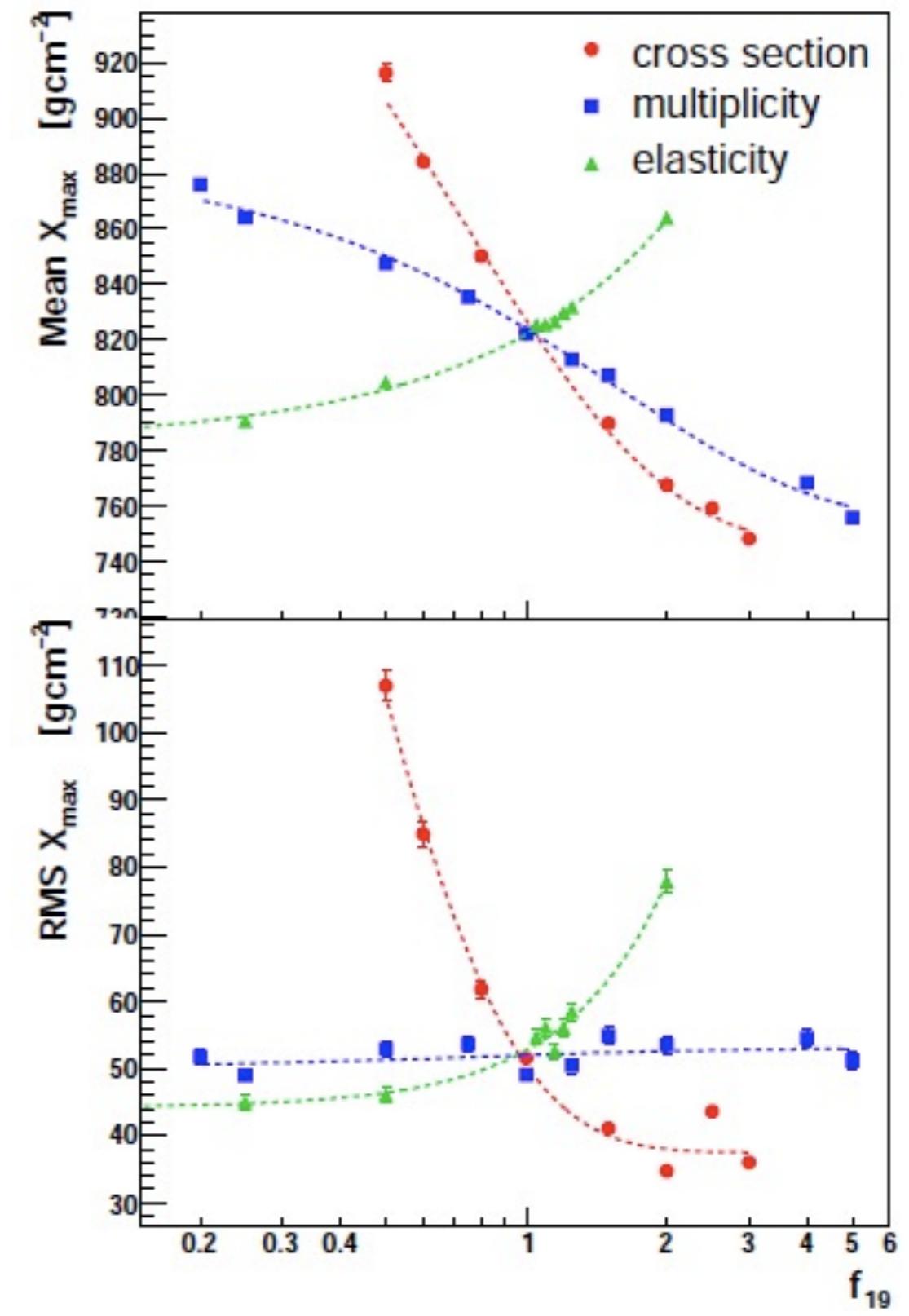
Are Changes to Hadronic Physics Responsible?

p-p cross section

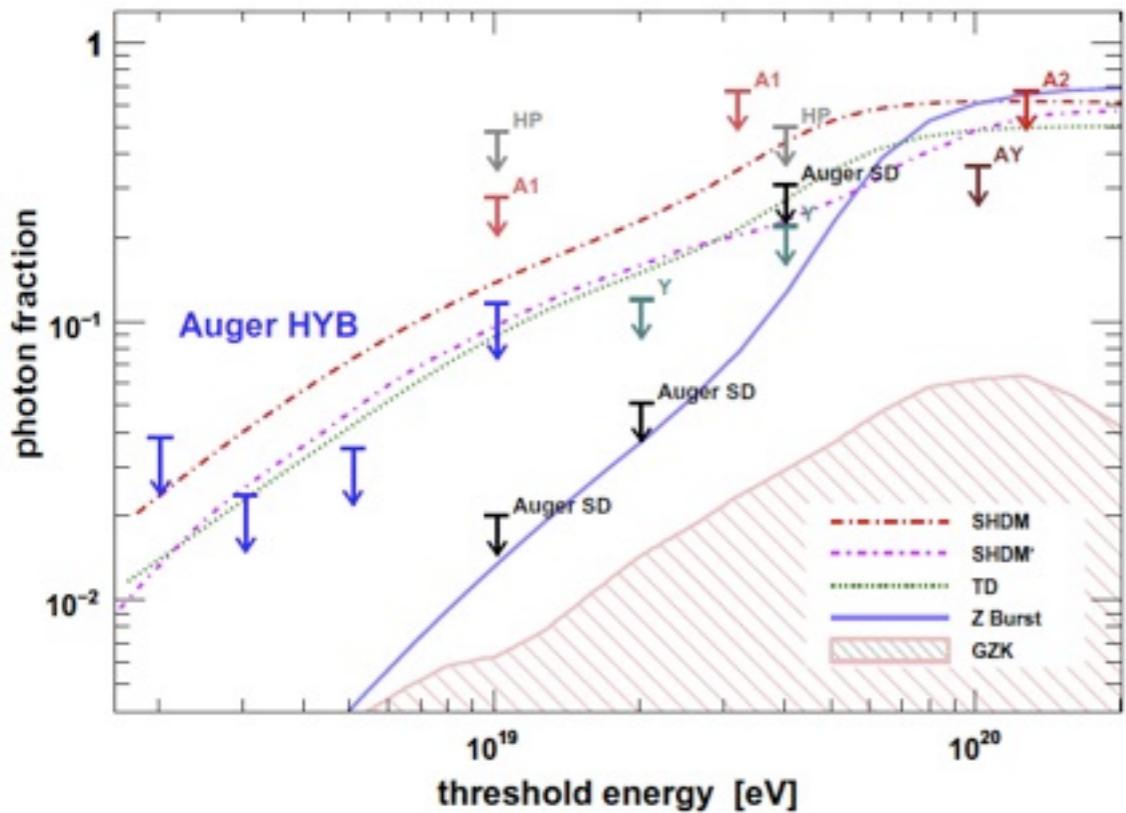


If CR are proton ->
hadronic interaction models to refine

- Find that mean X_{\max} is easier to influence than the RMS
- extreme changes to proton-air cross section required to explain RMS

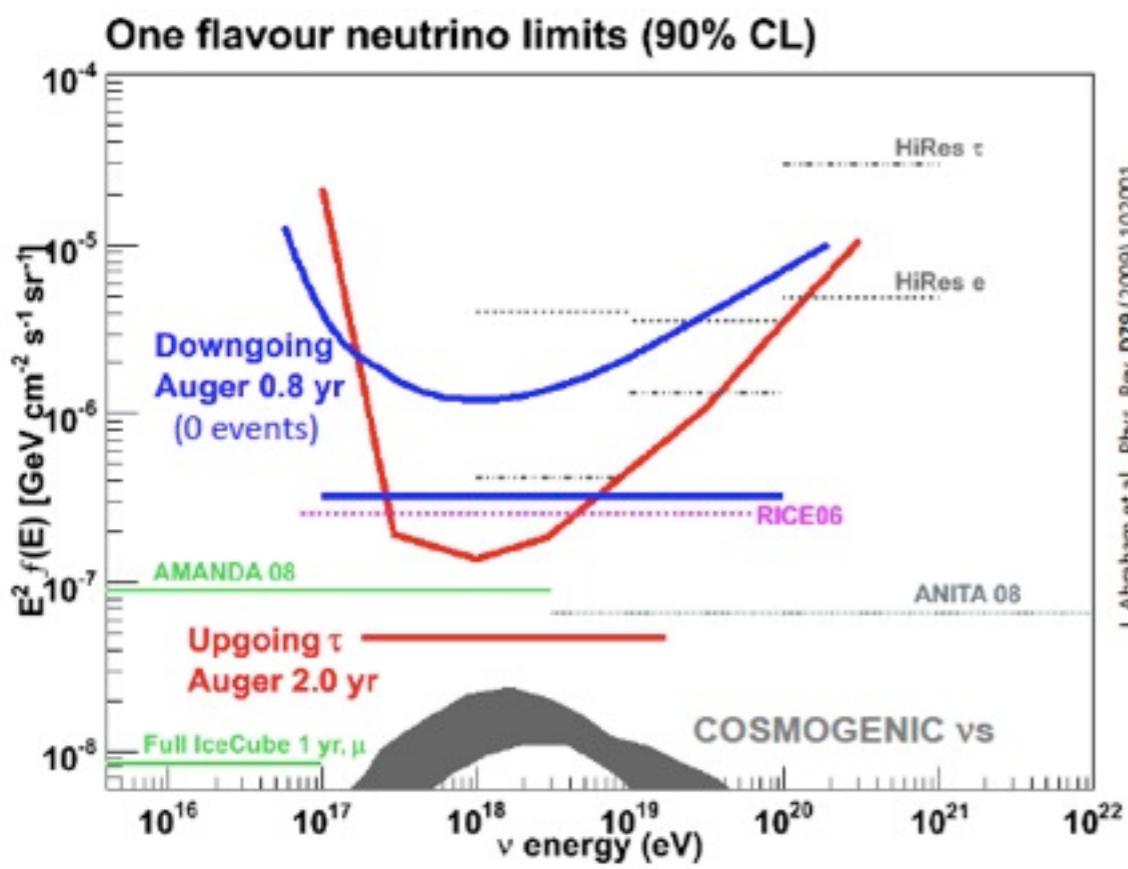


Photons and neutrinos limits



Photons

- FD and SD techniques
- top-down models highly constrained
- GZK photons \sim within reach
(but 20 years for current aperture)



Neutrinos

- SD limits from “young” inclined showers
- up-going (τ) and downgoing (all flavours)
- cosmogenic neutrinos within reach within lifetime of Auger south, if they exist....

Summary

What Auger showed us

- a significant spectral suppression above $10^{19.6}$ eV
- a weaker AGN correlation, but with interesting future targets
- a change in shower development with E – mass increase, or hadronic physics?
Tension with anisotropy?
- no photons and neutrinos so far, several exotic models ruled out

Next steps

- continue accumulating 7000 km²sr exposure every year
- continue to develop new analysis (e.g. SD mass composition)
- extend energy reach downwards
- strive for longer exposure, new cheaper techniques, larger area

Puzzling results, driving the need to go further to understand
Mass composition is the key !

Auger Enhancements/New Techniques

High Elevation Telescopes (HEAT)

20 km² radio antenna field

Infill and Muon Detector (AMIGA)