PIERRE
AUGER
OBSERVATORY

Recent results from the Pierre Auger Observatory

CosPa 2013

Honolulu, Hawaii, USA

Harm Schoorlemmer[1] for the Pierre Auger Collaboration

[1]University of Hawaii at Manoa

Auger ICRC 2013: arXiv:1307.5059

Auger + TA: arXiv:1310.0647

Outline

- Observatory and Performance

- Energy Calibration and Energy spectrum

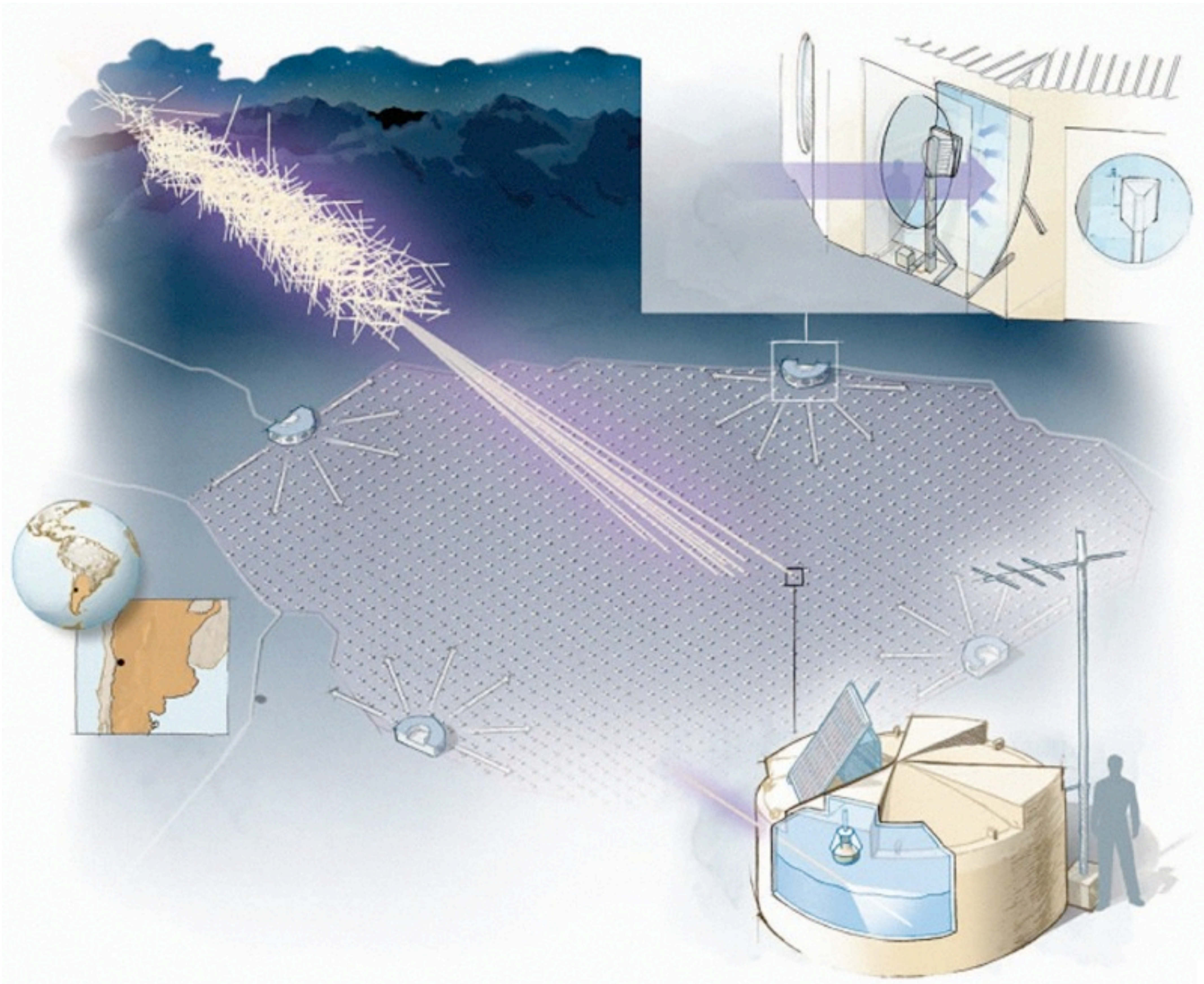
- Mass composition and Hadronic interactions

- Large scale anisotropy

Collaboration : ~ 500 members & 19 countries

Argentina
Australia
Brazil
Croatia
Czech Republic
France
Germany
Italy
Mexico
Netherlands
Poland
Portugal
Slovenia
Spain
United Kingdom
USA

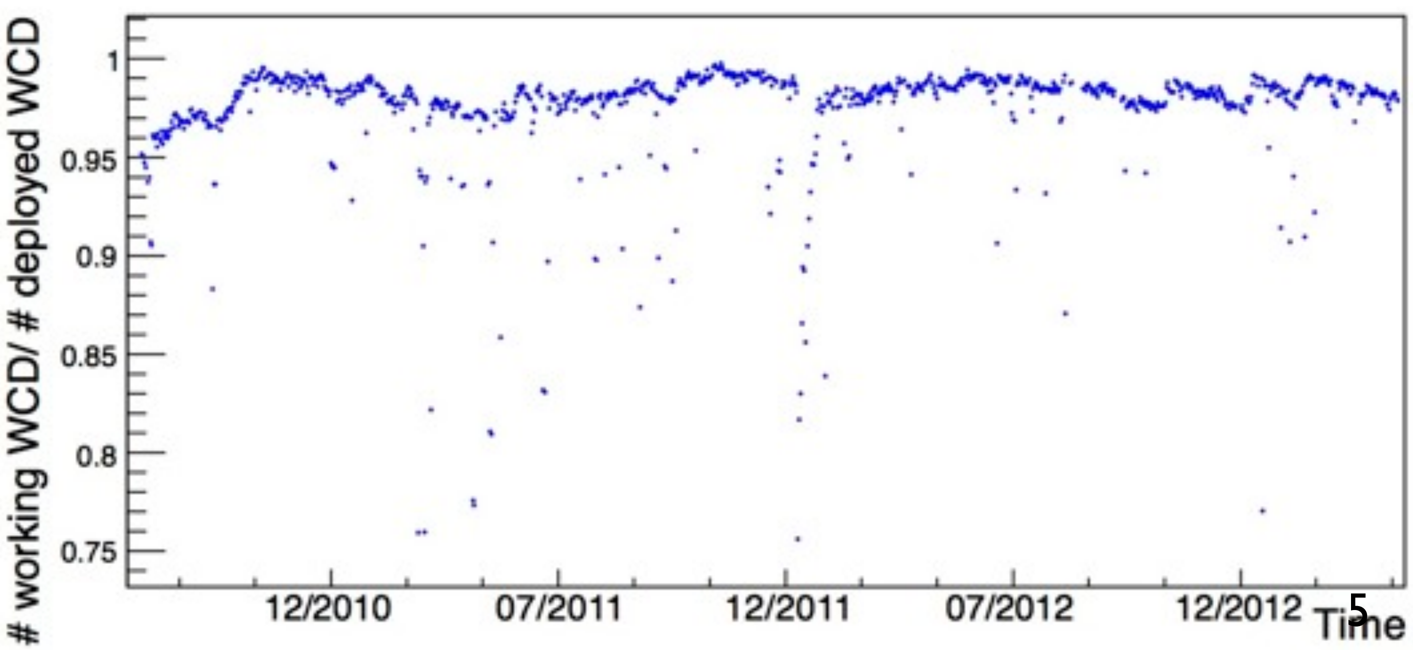
Bolivia*
Romania*
Vietnam*
*Associated

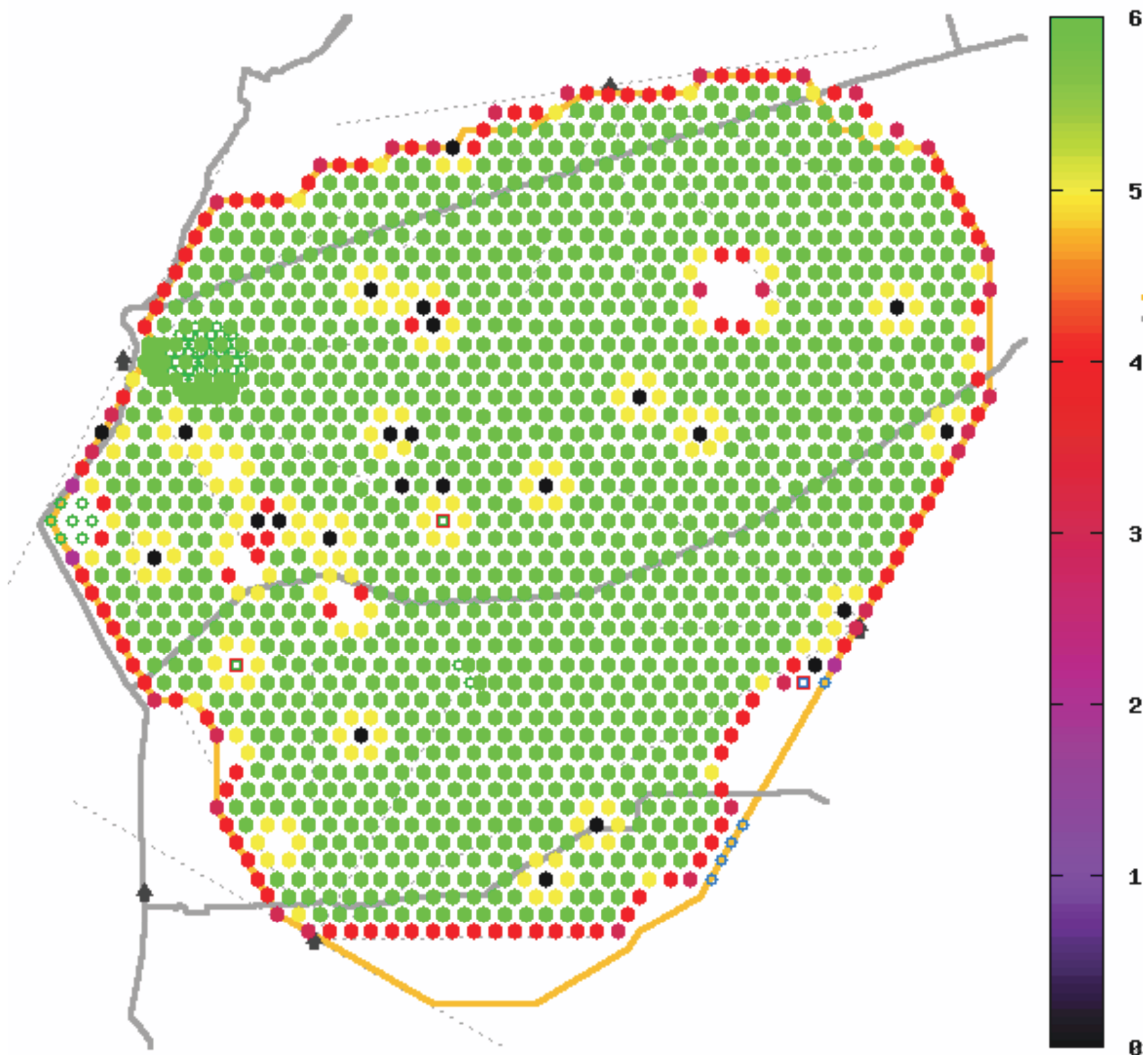


The surface detector: 1660 Water-Cherenkov Detectors

Regular Array, triangular grid of 1500m spacing:
$E > 3 \times 10^{18}$eV
Infill Array, triangular grid of 750m spacing:
$E > 3 \times 10^{17}$eV

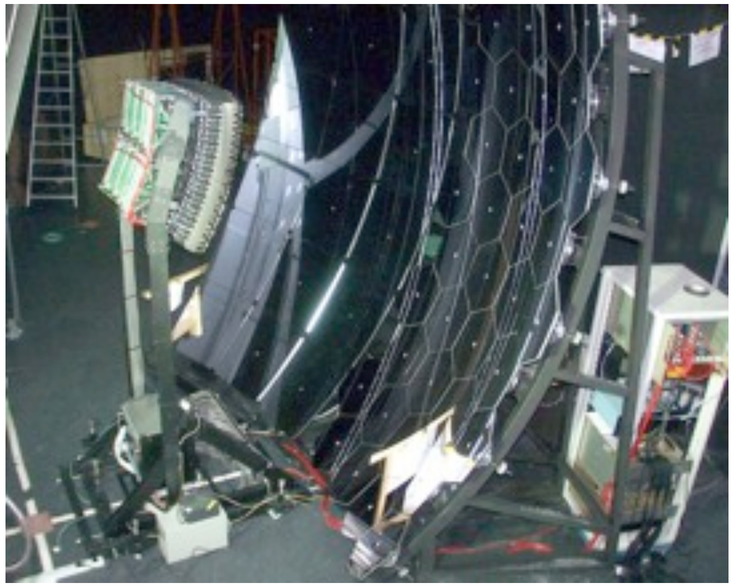
Performance:



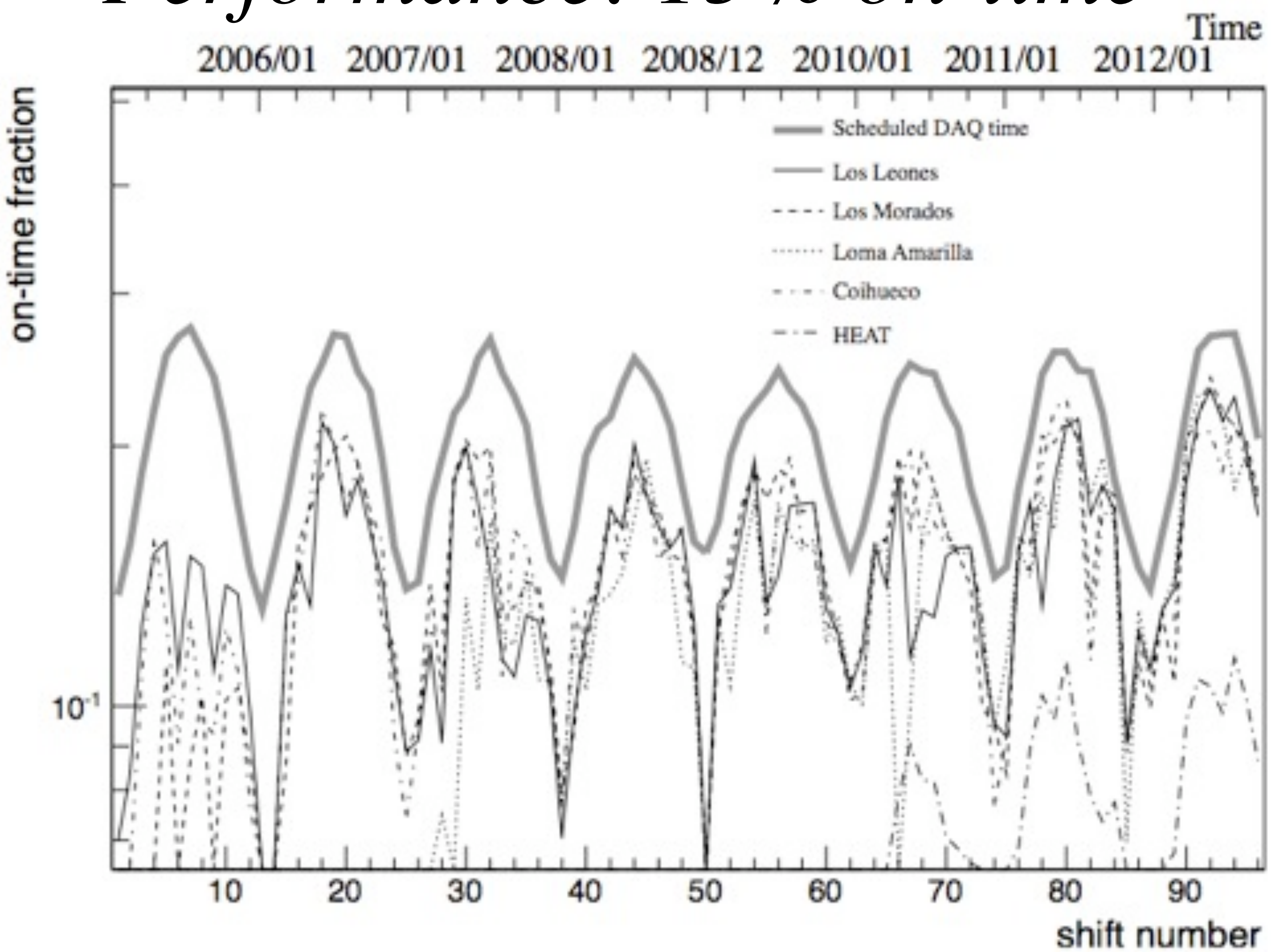


The fluorescence detector: 27 telescopes

4 sites with 6 telescopes + 3 High Elevation Telescopes



Performance: 13% on-time



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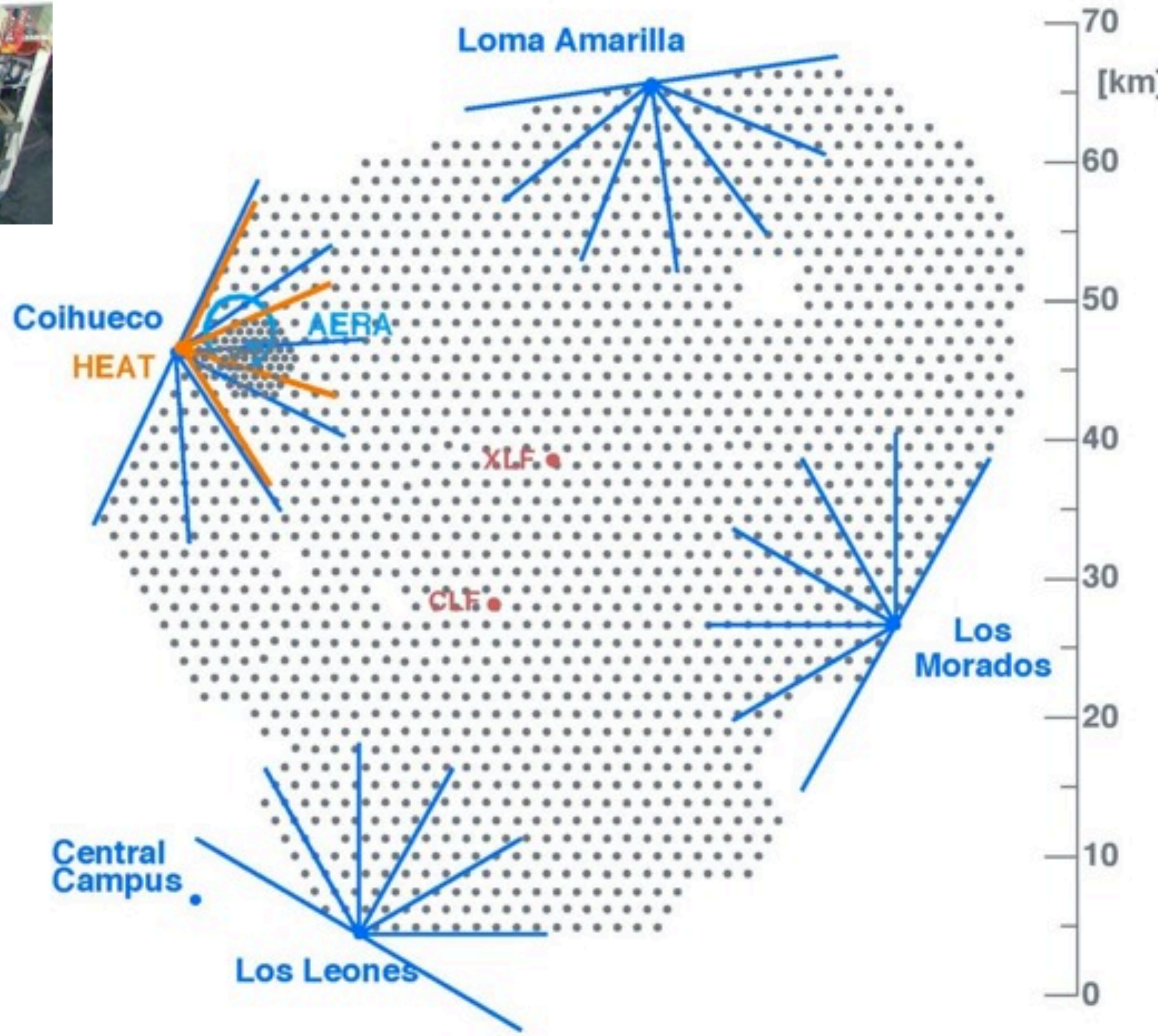


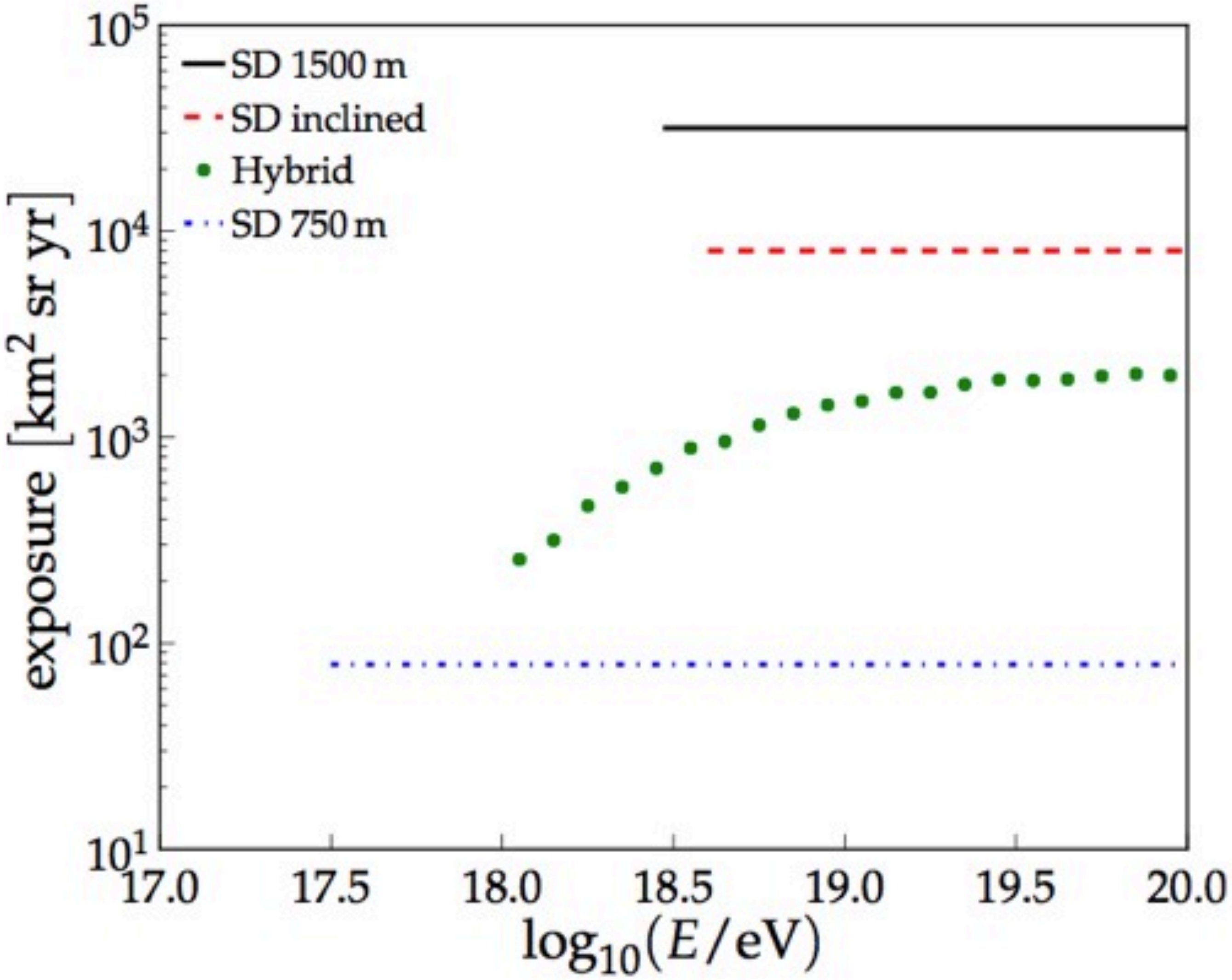
The absolute energy scale

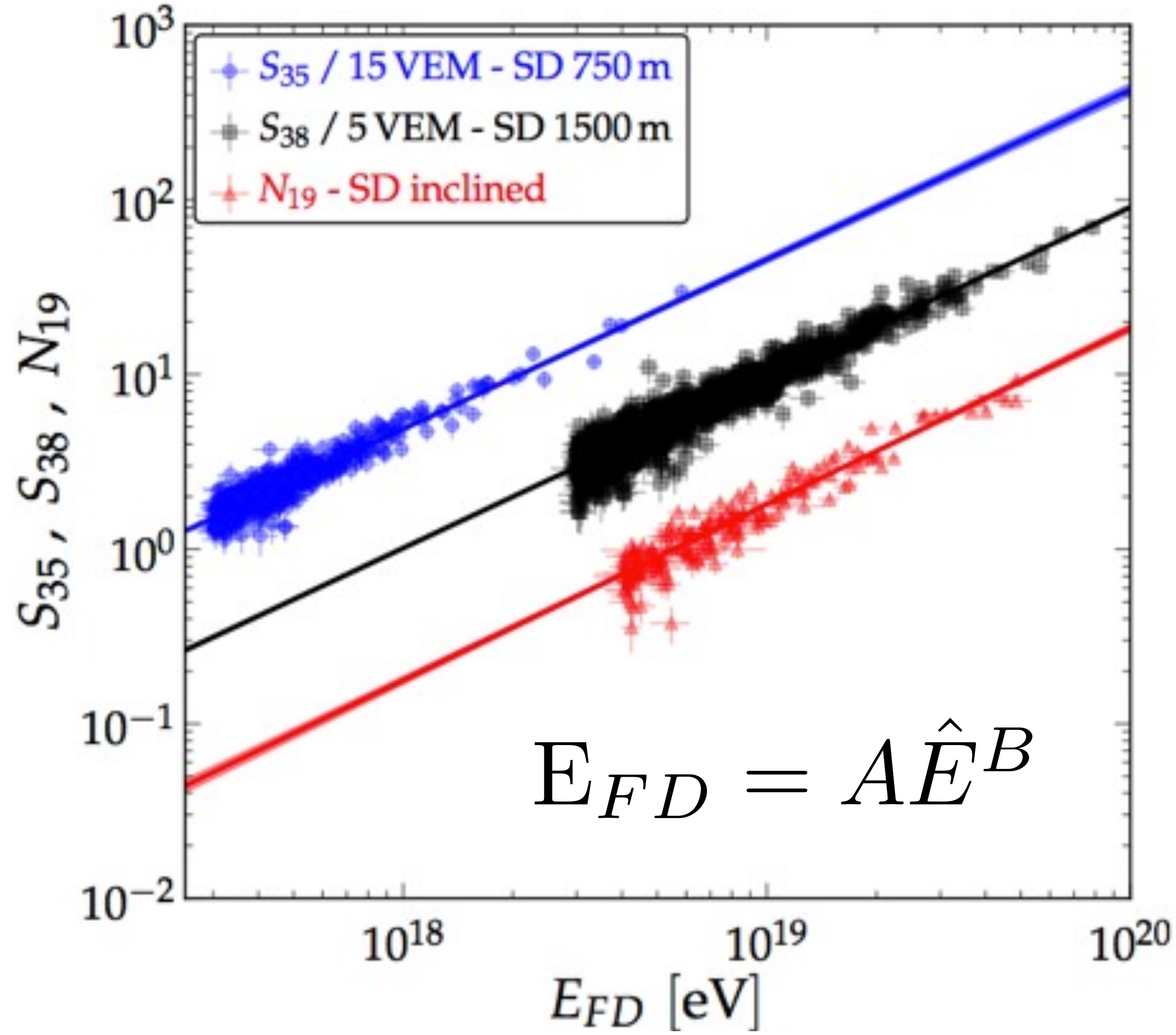
-The fluorescence telescopes provide a nearly calorimetric measurement of the air shower
-Recent improvements in calibration and reconstruction shifted the energy scale by **15.6%** and reduced the systematic error on it from 22% to **14%**

Fluorescence Yield:	-8.2%
Calibration:	+7.8%
Reconstruction of the longitudinal profile:	+11.6%
Invisible energy:	+4.4%

Measuring the point spread function with a light source on an octocopter

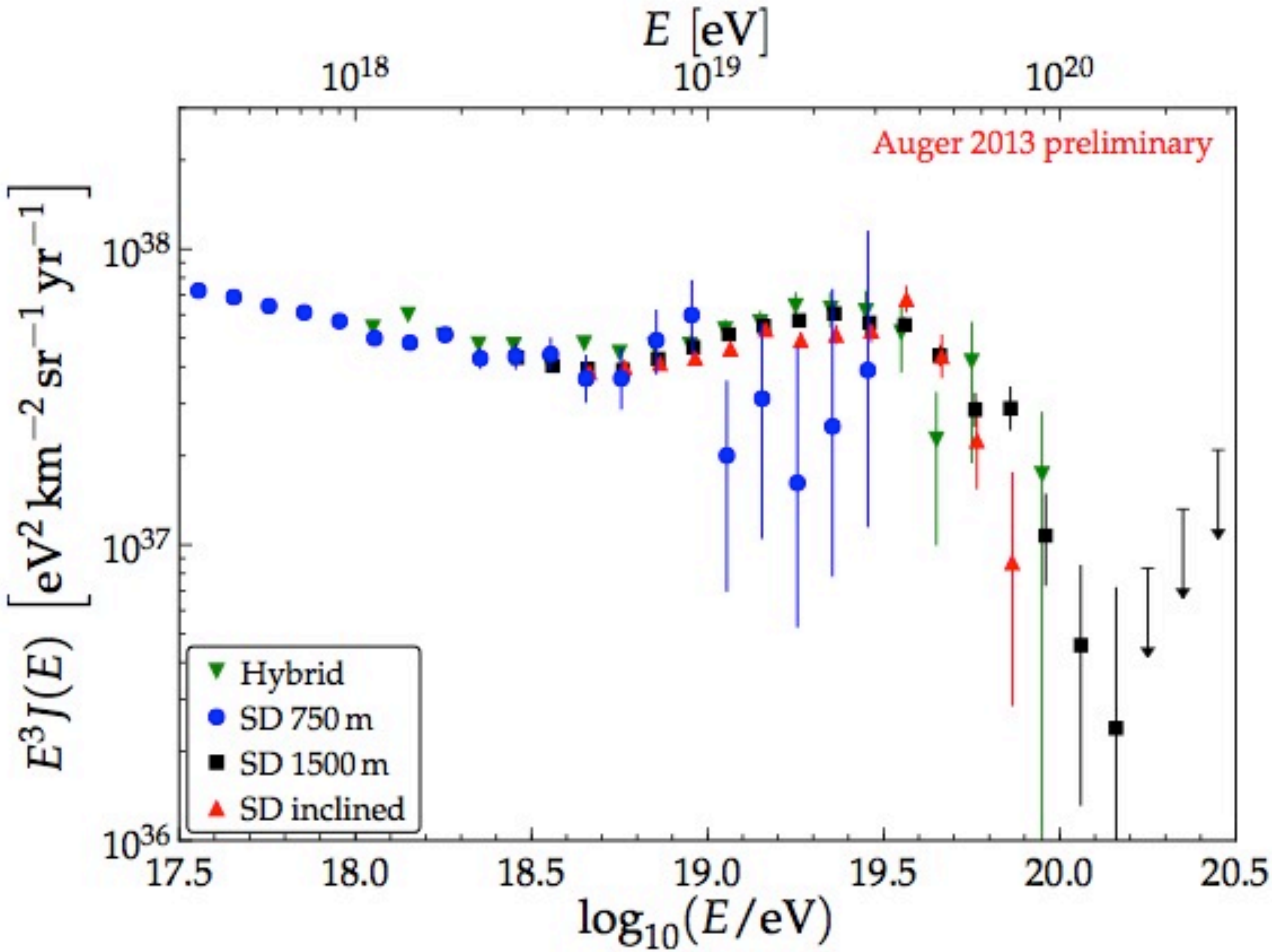
The Exposure and Energy Estimators



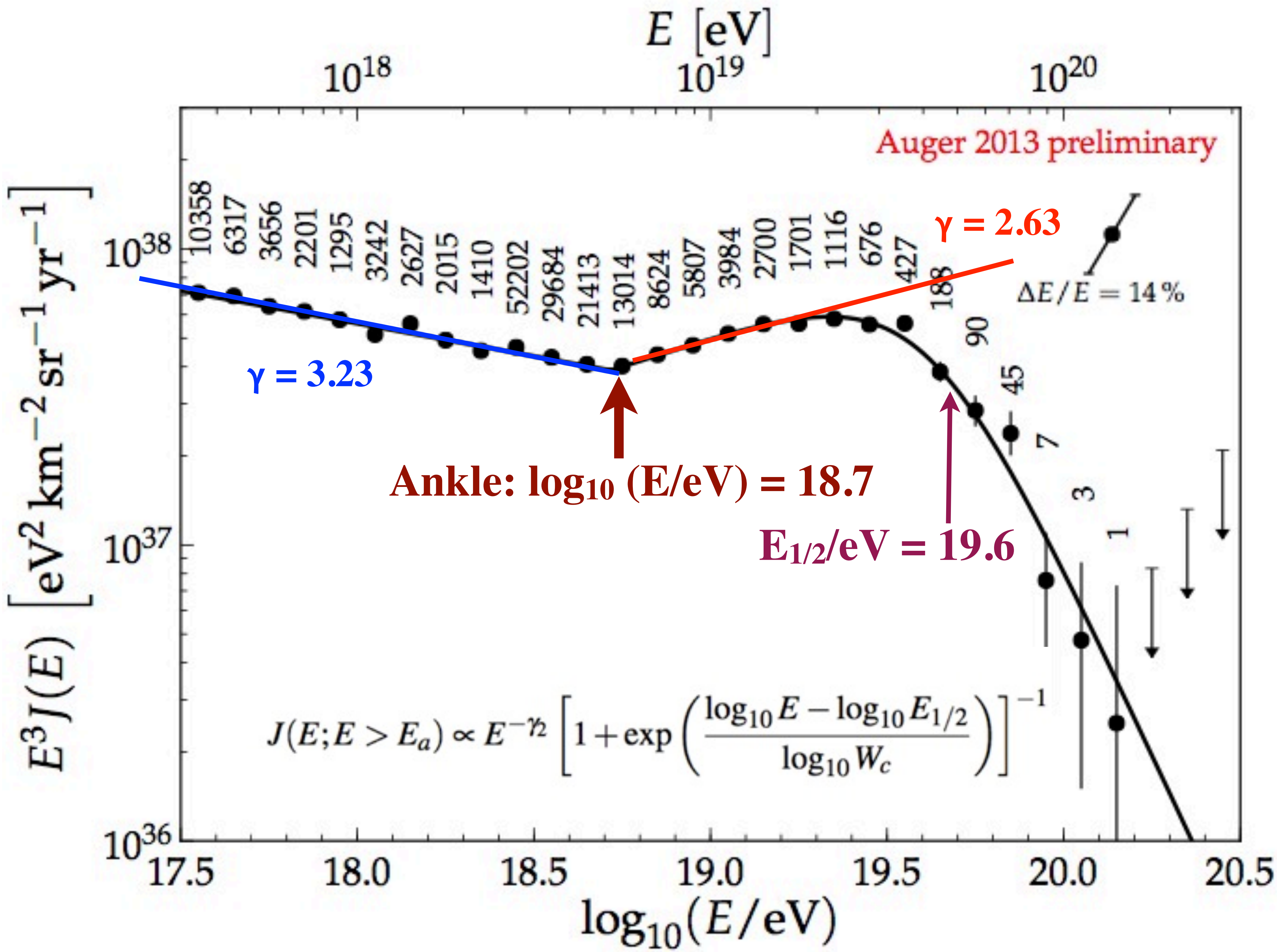


	Auger SD			Auger hybrid
	1500 m vertical	**1500 m inclined**	**750 m vertical**	
Data taking period	01/2004 - 12/2012	01/2004 - 12/2012	08/2008 - 12/2012	11/2005 - 12/2012
Exposure [km^2 sr yr]	31645 ± 950	8027 ± 240	79 ± 4	see Fig. 1
Zenith angles [°]	$0-60$	$62-80$	$0-55$	$0-60$
Threshold energy E_{eff} [eV]	3×10^{18}	4×10^{18}	3×10^{17}	10^{18}
No. of events ($E > E_{\mathrm{eff}}$)	82318	11074	29585	11155
No. of events (golden hybrids)	1475	175	414	-
Energy calibration (A) [EeV]	0.190 ± 0.005	5.61 ± 0.1	$(1.21 \pm 0.07) \cdot 10^{-2}$	-
Energy calibration (B)	1.025 ± 0.007	0.985 ± 0.02	1.03 ± 0.02	-

The Auger Energy Spectrum



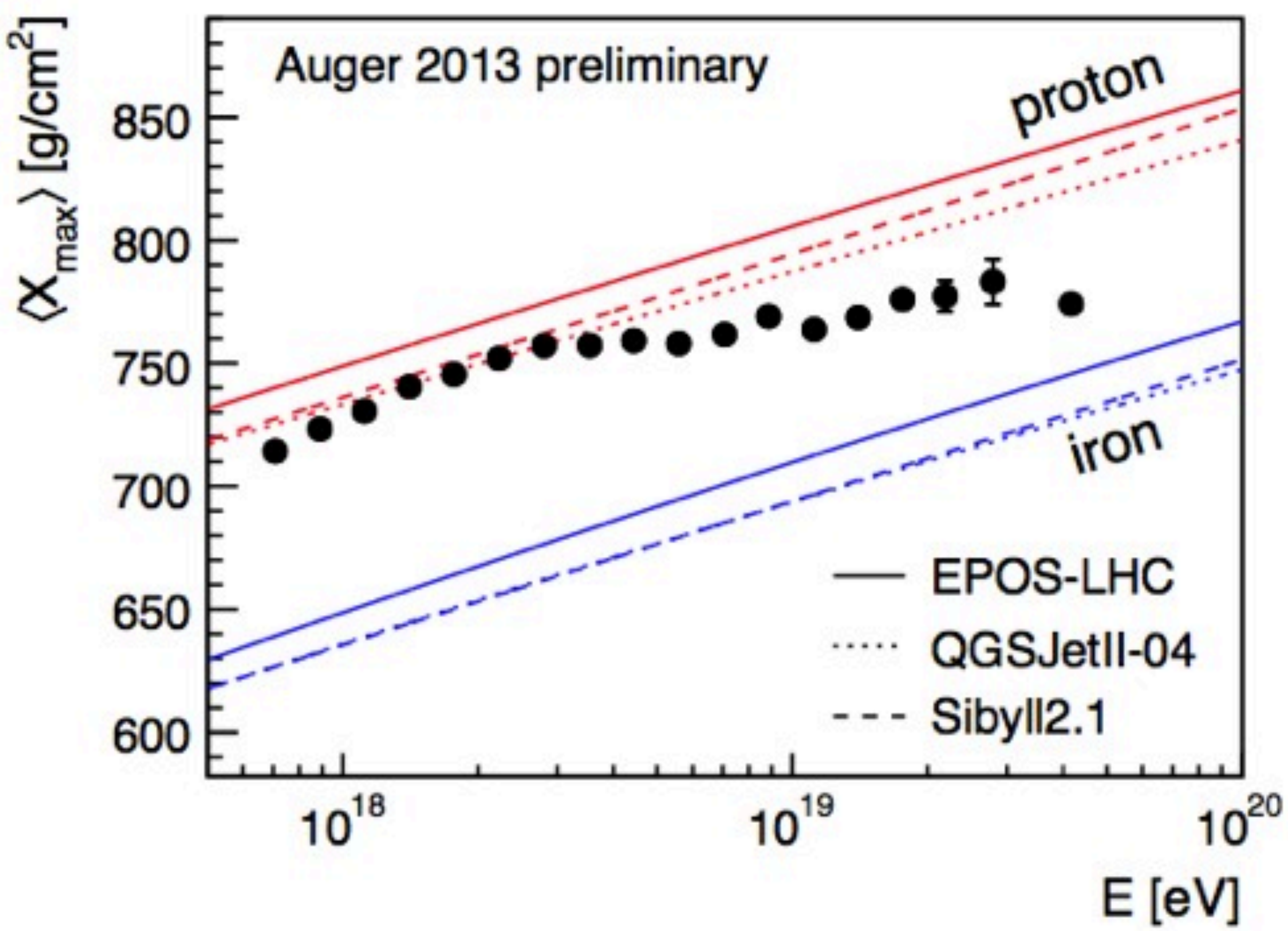
The Auger Energy Spectrum

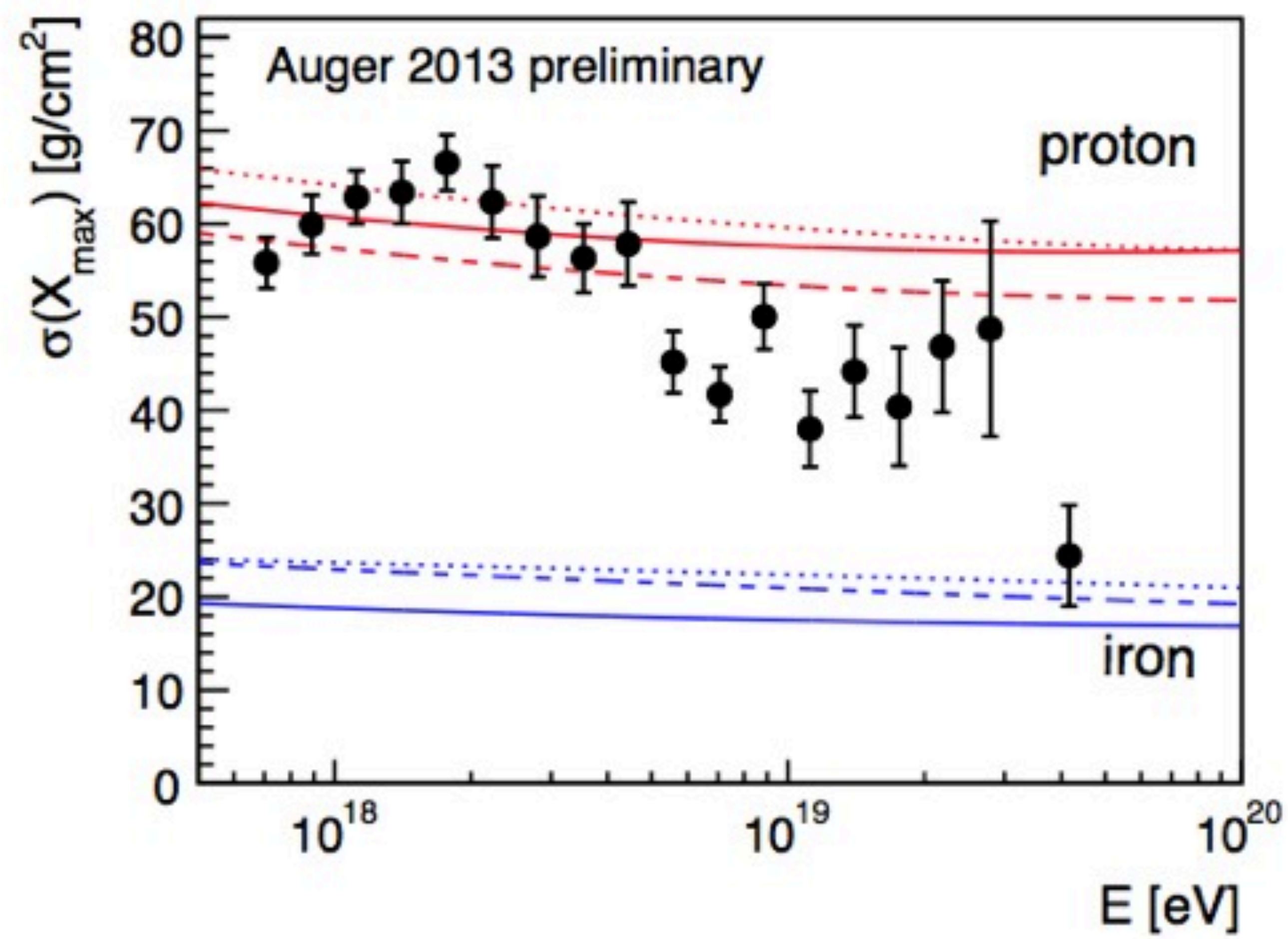


Normalization: hybrid -6%, inclined +4%, 750m array +2%, SD -1%

Mass Composition:

Evolution of the first two moments of the X_{max} distributions





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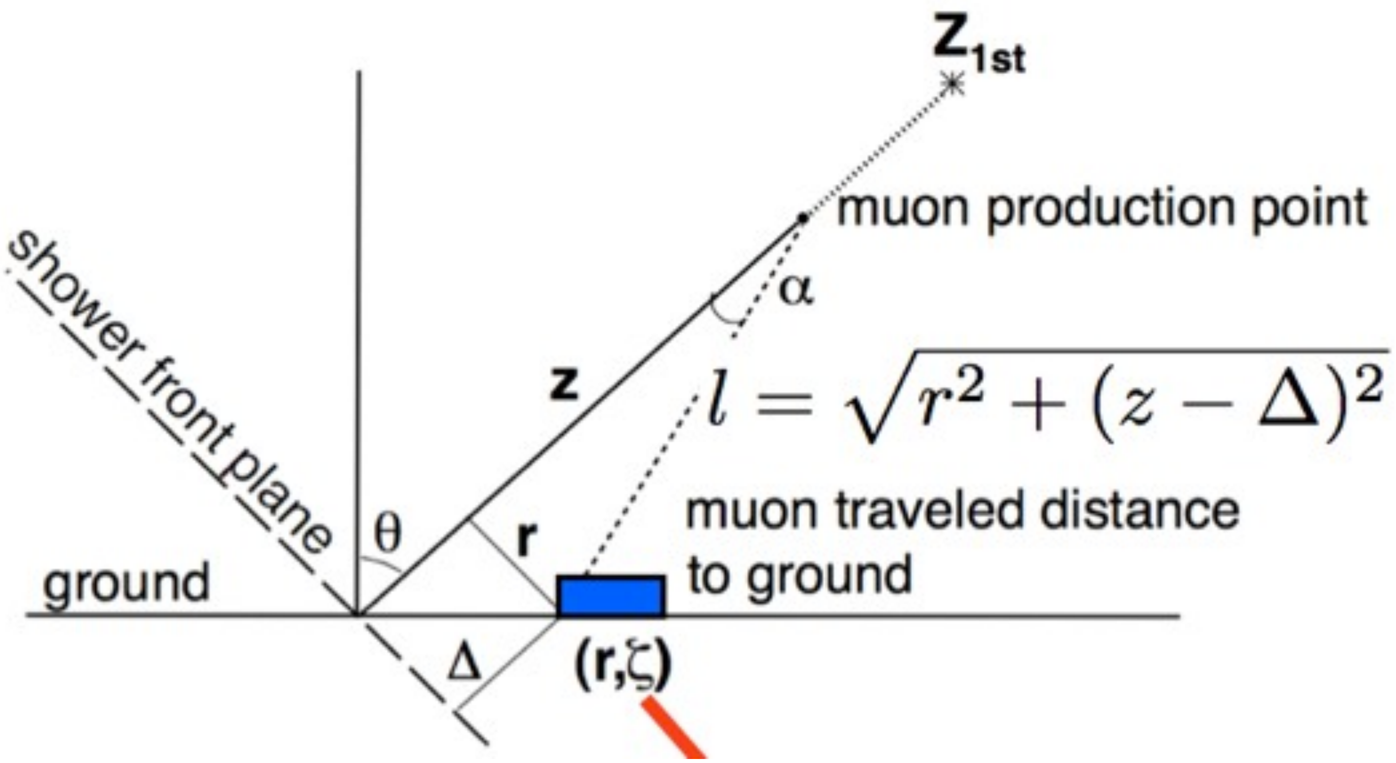
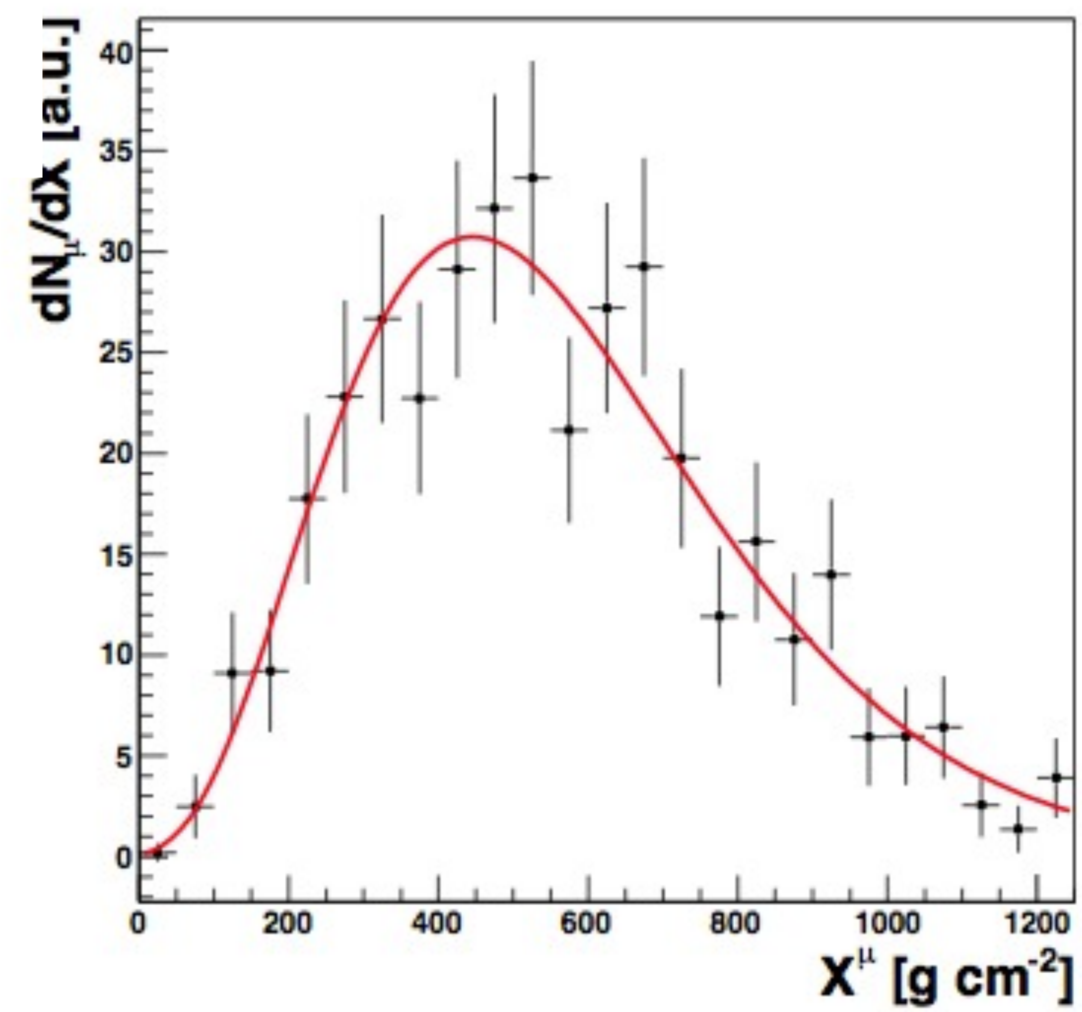
Mass Composition: Muon production depth

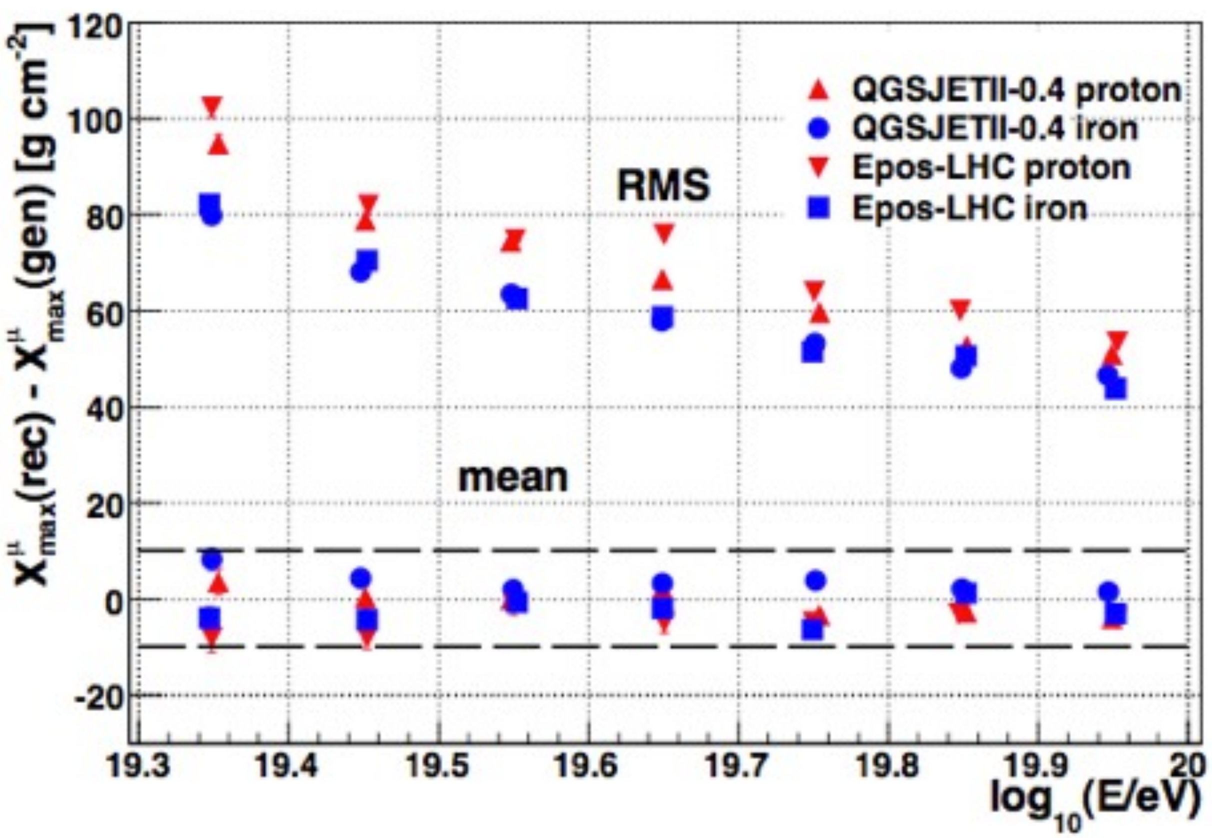


From time delay we can estimate location of emittance on the shower axis

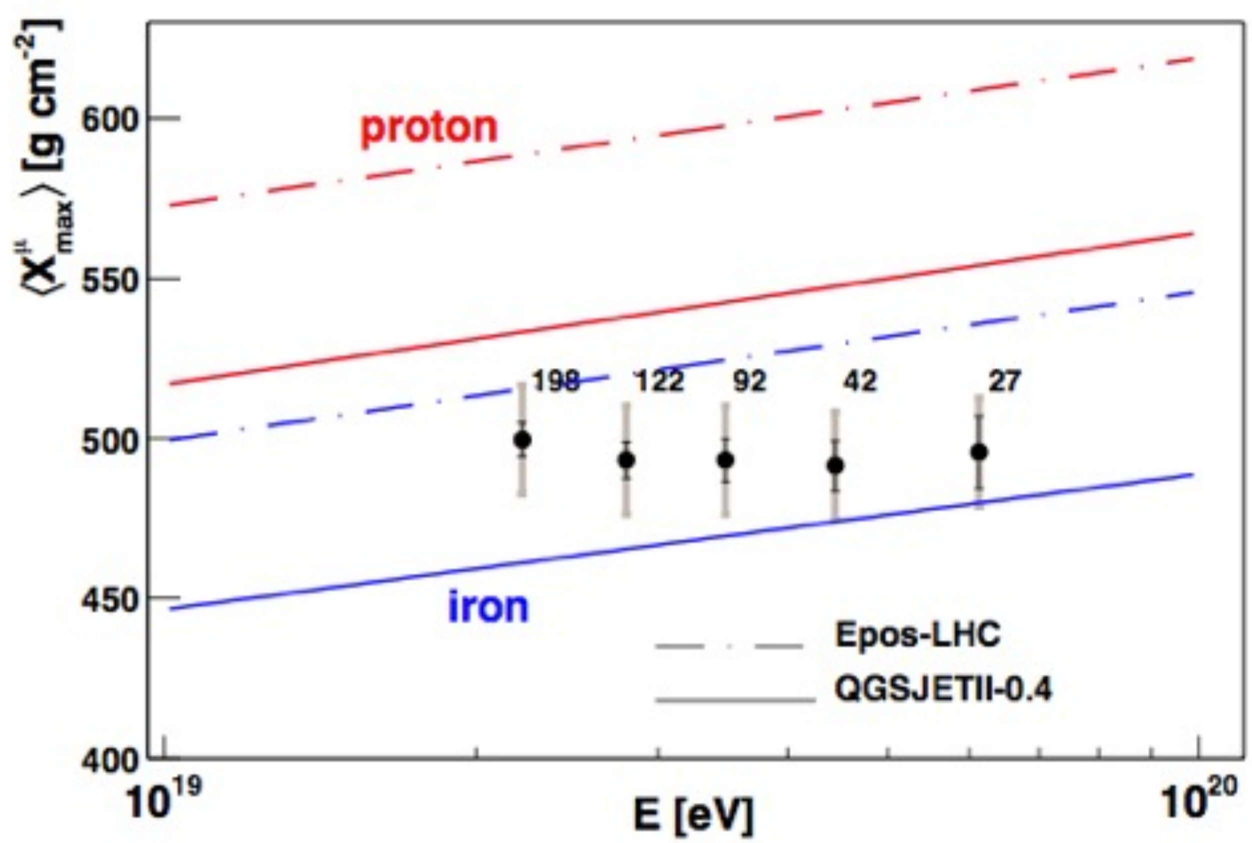


Mass Composition: Muon production depth

Validation on MC

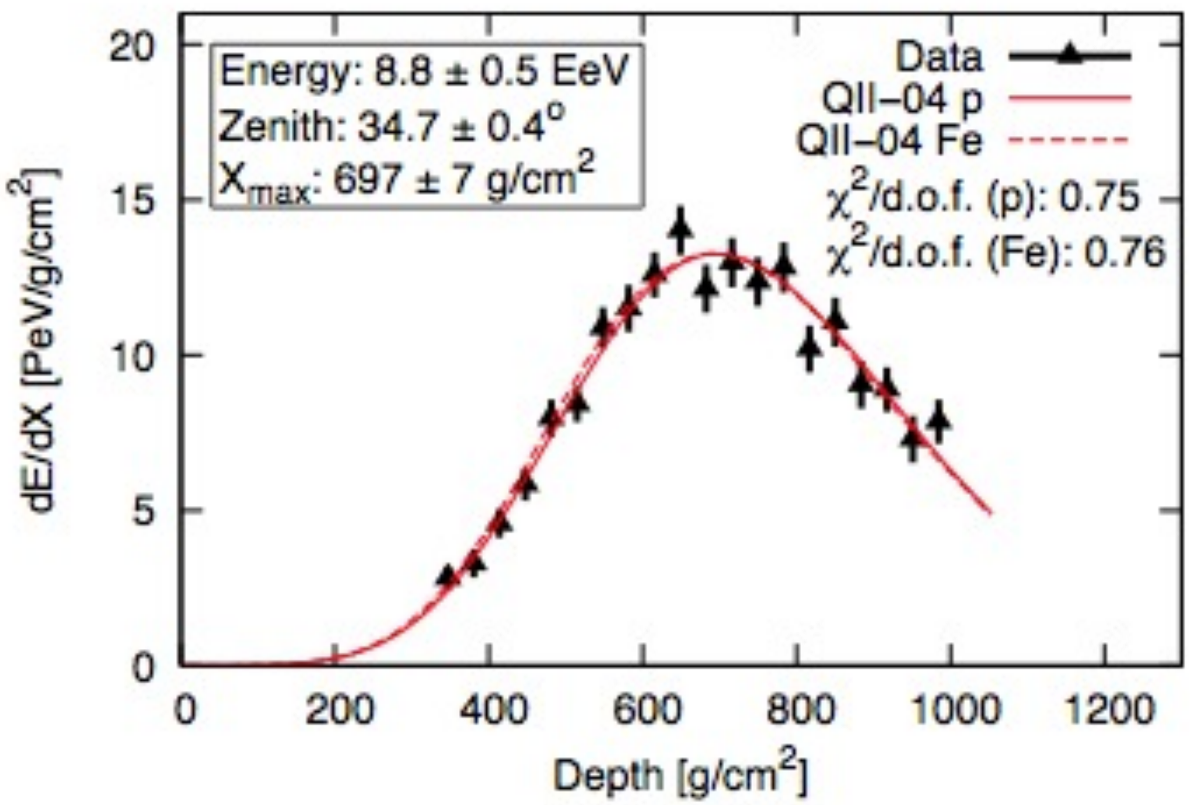


Results on data

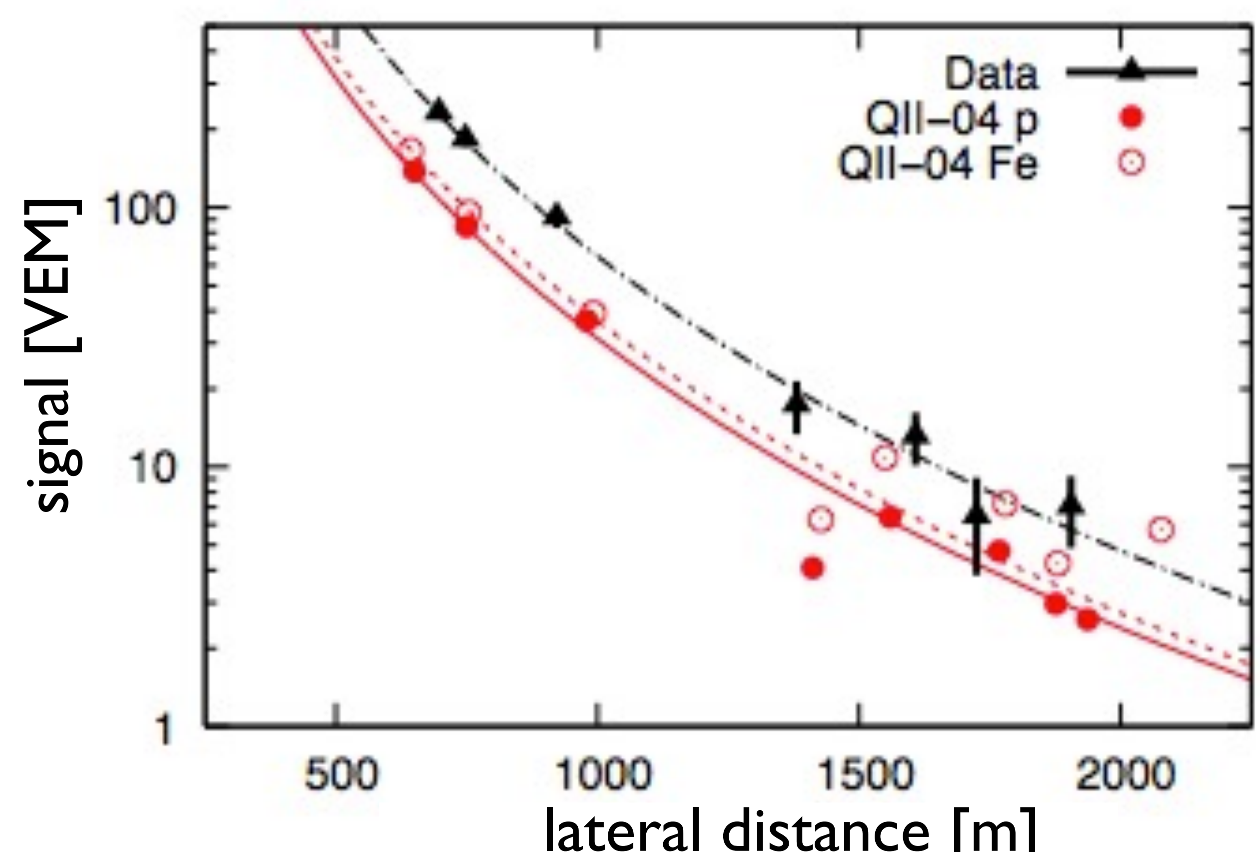


Hadronic interaction models and number of muons

Pick from simulations the best fit to the measured longitudinal shower profile for different primary particles.



Compare to observed signal on the ground to the expectation from the measurements.



Ground signal is higher than expectation!

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Hadronic interaction models and number of muons

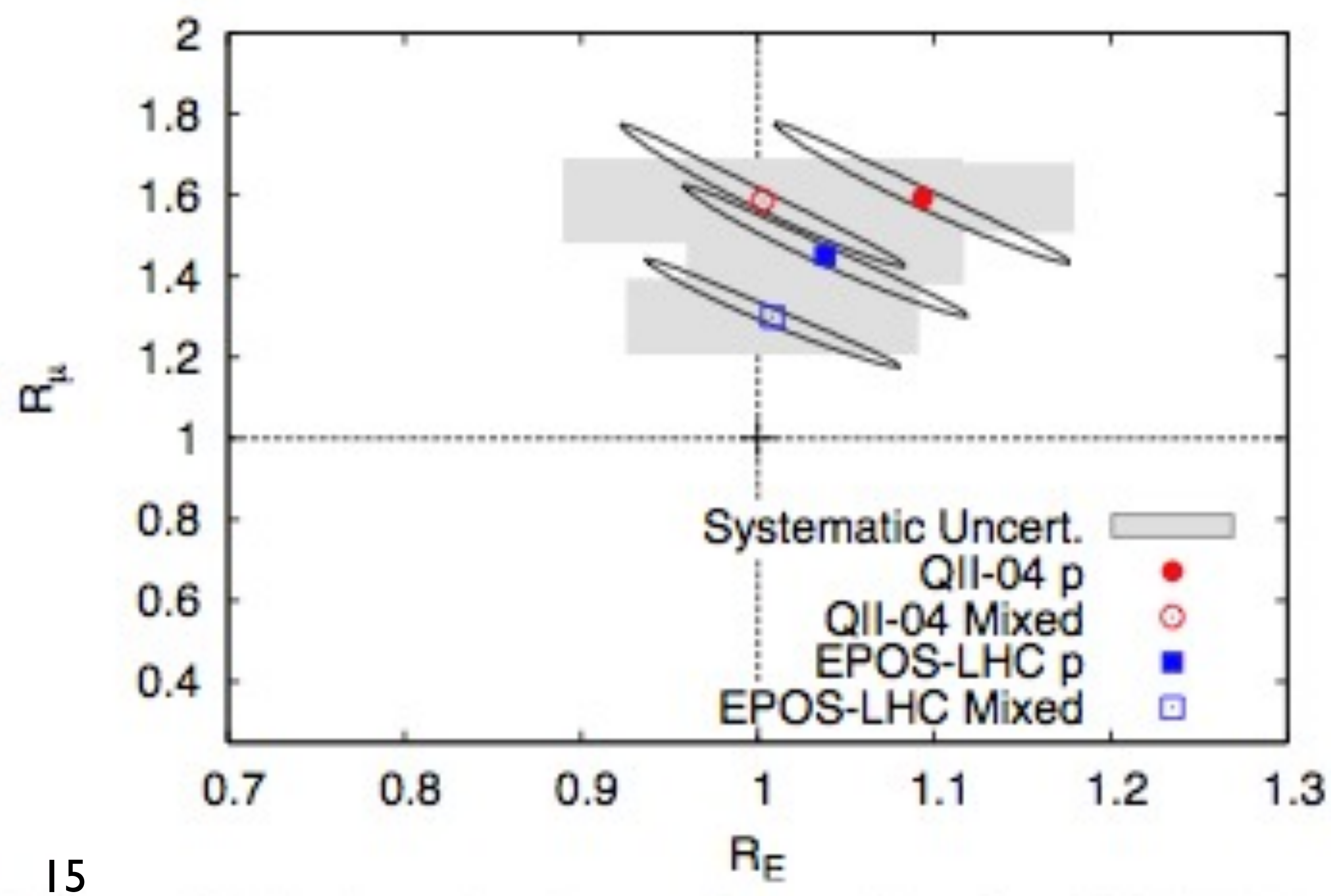
Fit the simulated ground signal using two rescaling factors:

R_μ rescale the number of muons from hadronic origin

R_E rescale the number of particles according to the energy of the primary particle

Hadronic interaction models underestimate the number of observed muons!!

Also confirmed by number of muons in inclined events, and from muon estimates from the time structure of the SD-PMT time series



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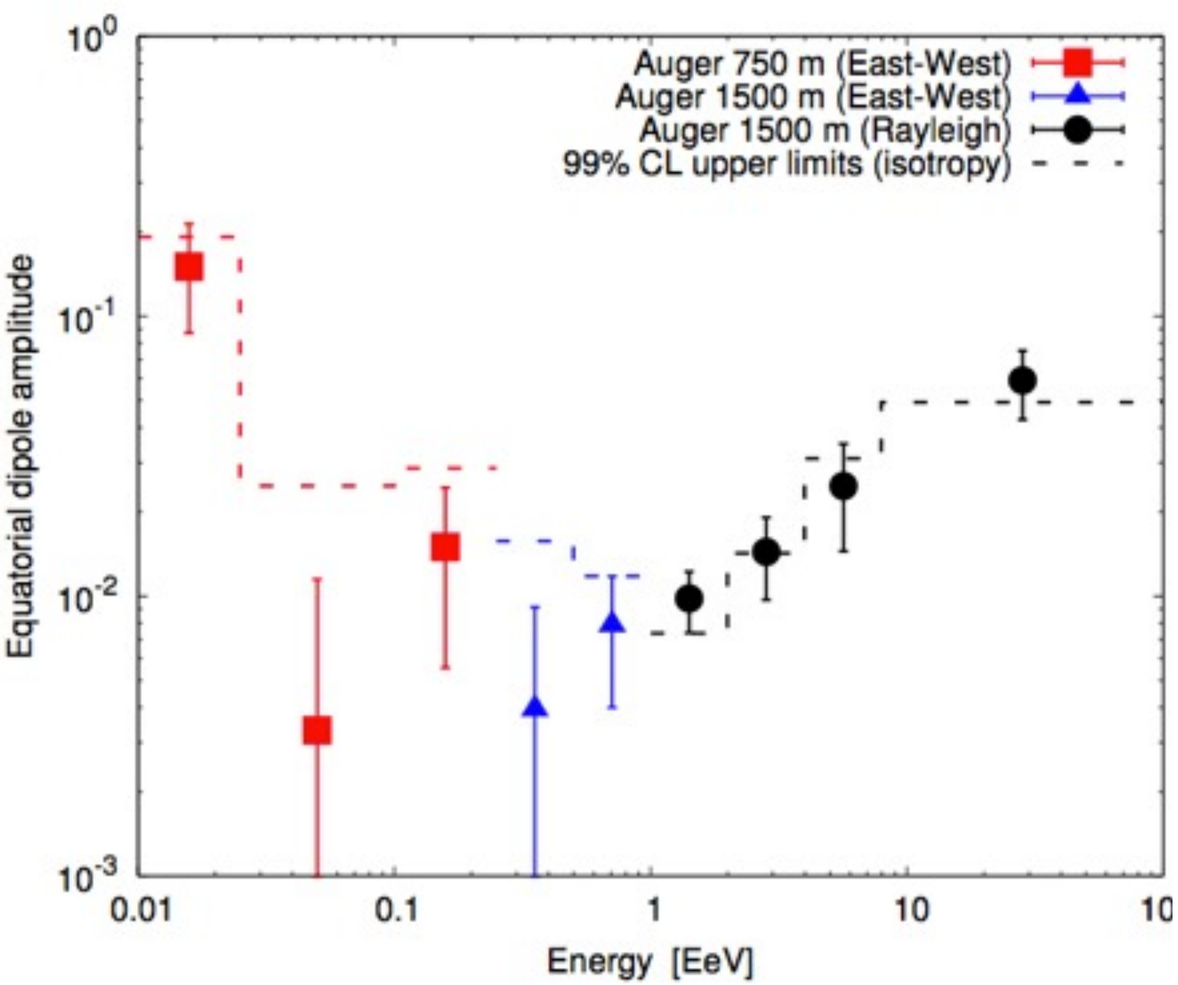
Large scale anisotropy

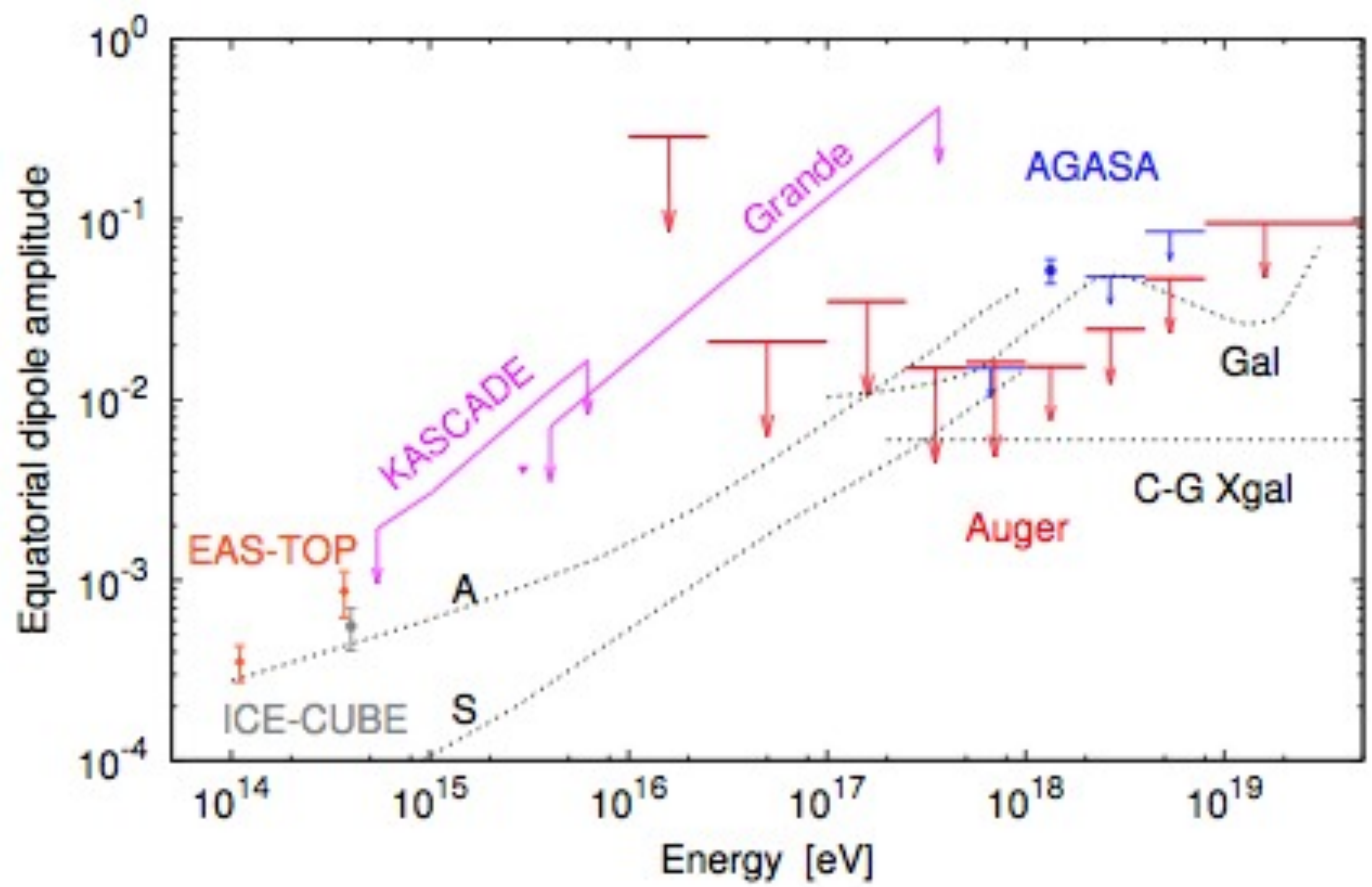
Equatorial dipole amplitude

$$a = \frac{1}{\hat{N}} \sum_i^N w_i \cos(\alpha_i)$$

$$b = \frac{1}{\hat{N}} \sum_i^N w_i \sin(\alpha_i)$$

$$r = \sqrt{a^2 + b^2}$$





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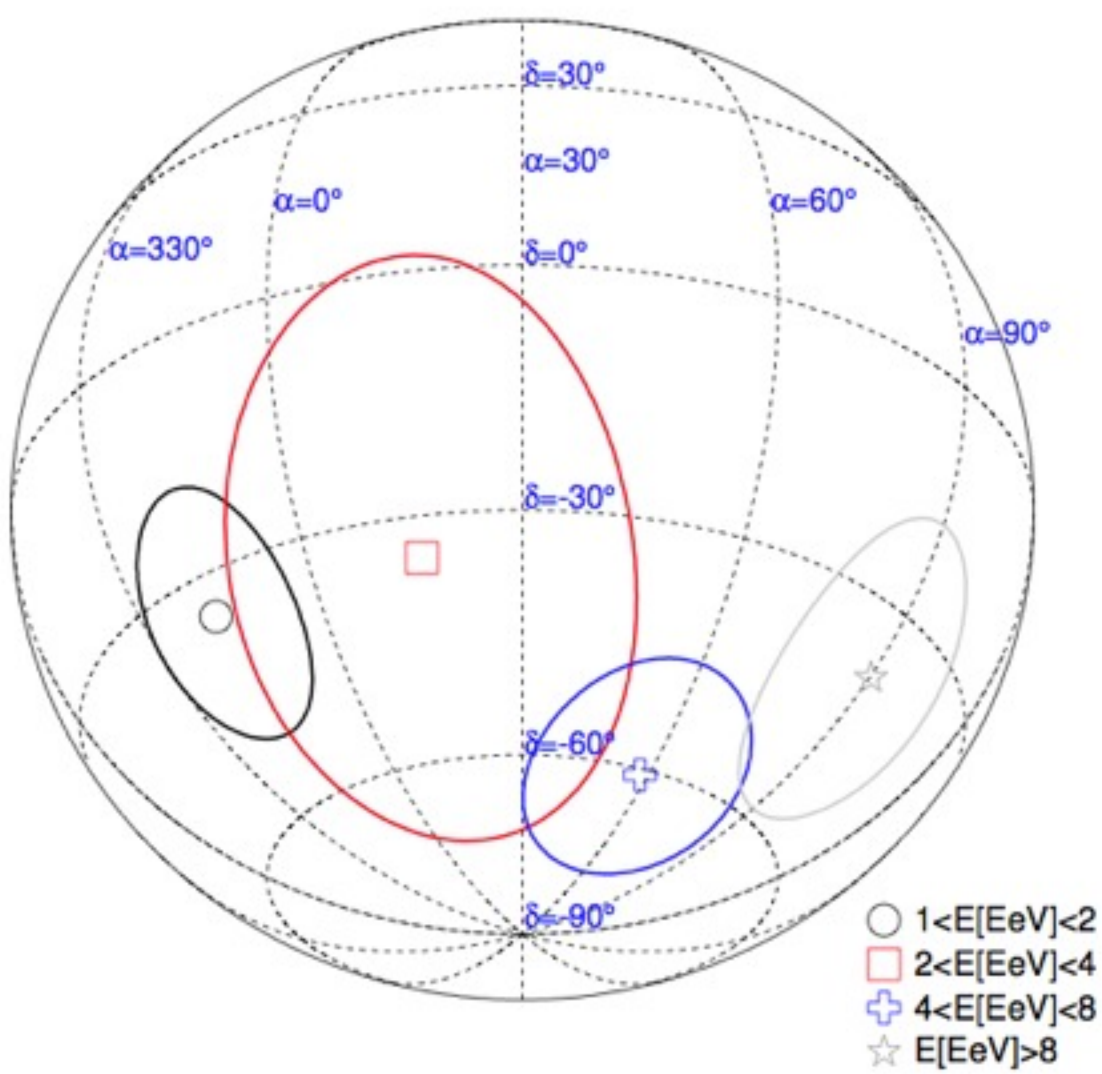
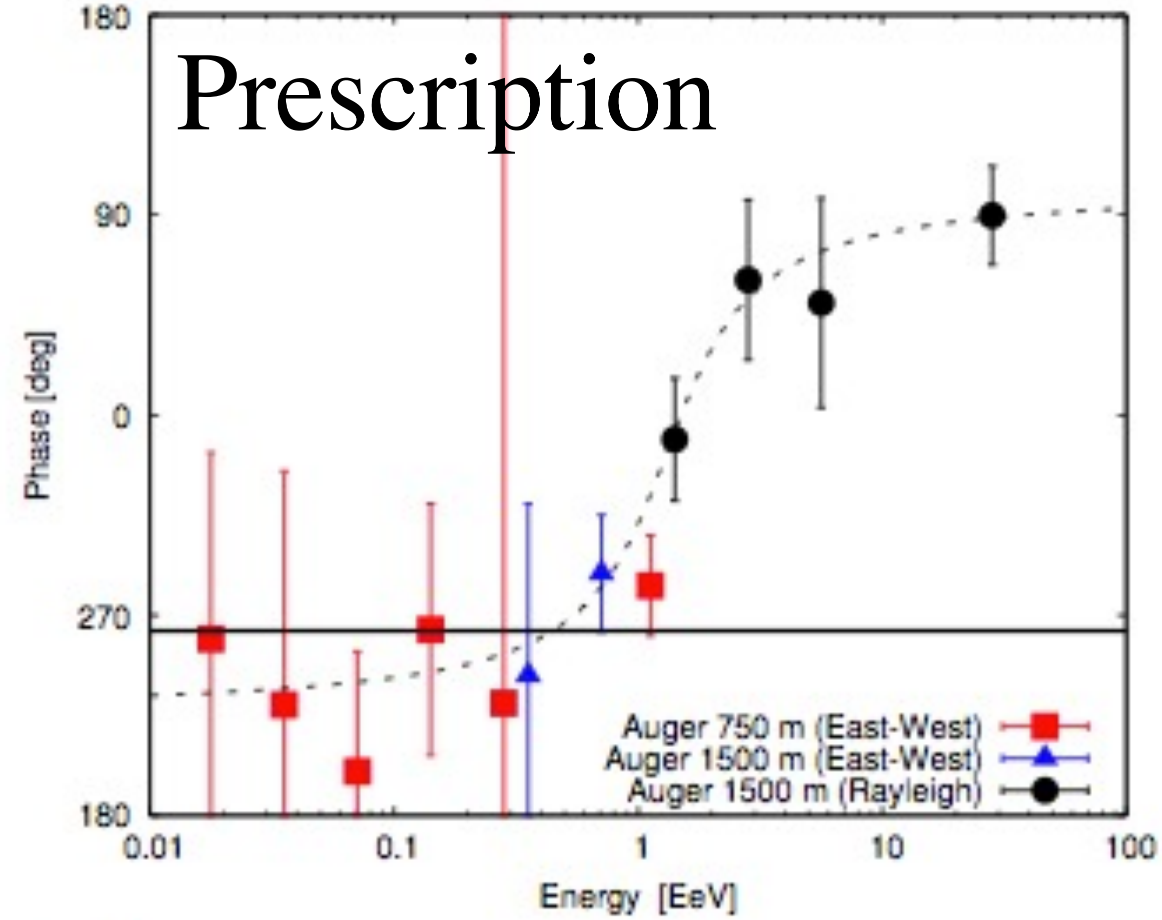
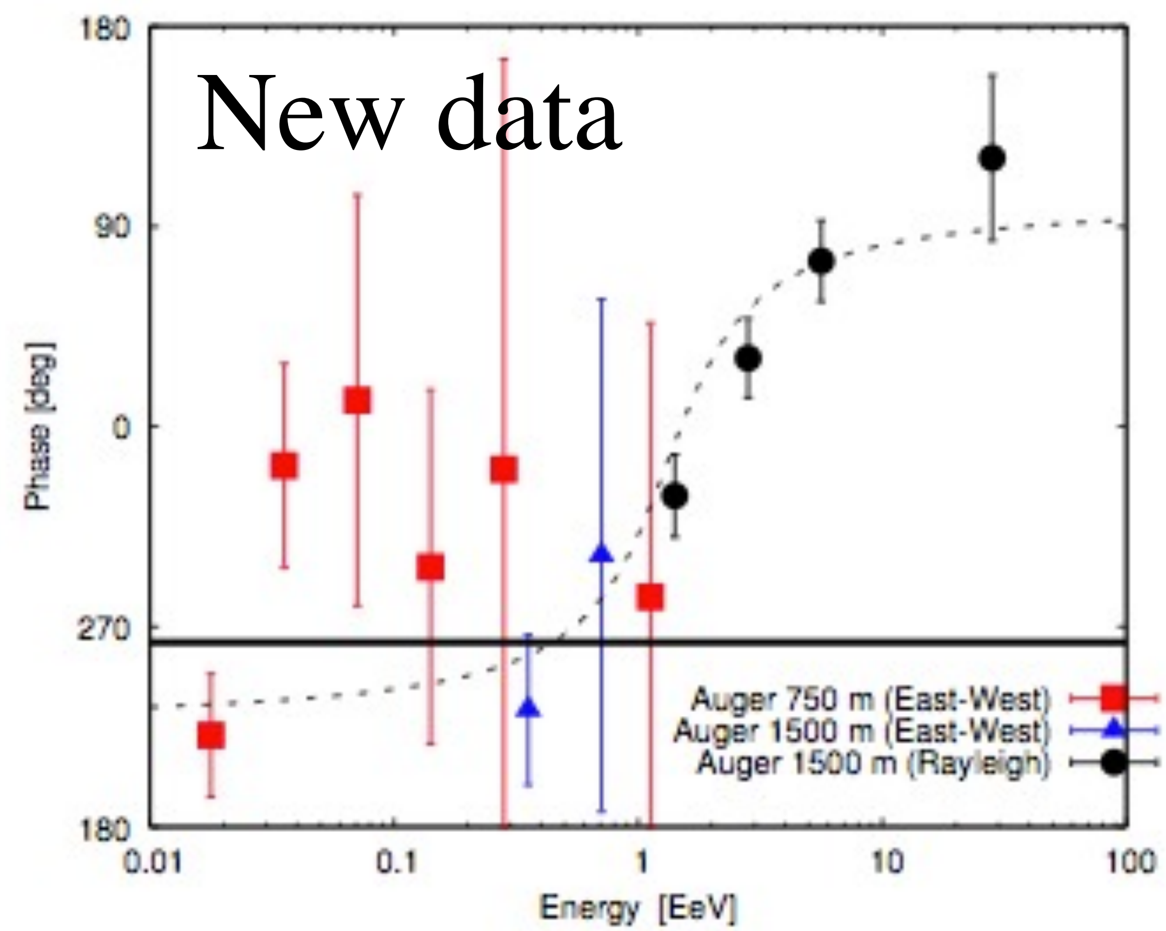
Large scale anisotropy

Equatorial dipole phase

$$\phi = \arctan\left(\frac{b}{a}\right)$$







Conclusions

Energy scale understood to 15%

The Pierre Auger Observatory provides the measurements to test high energy hadronic interaction models

Large scale anisotropies start to look interesting!!

And there is more: radio detection, extensions, neutrino flux limits, neutron flux limits, joint efforts with the telescope array

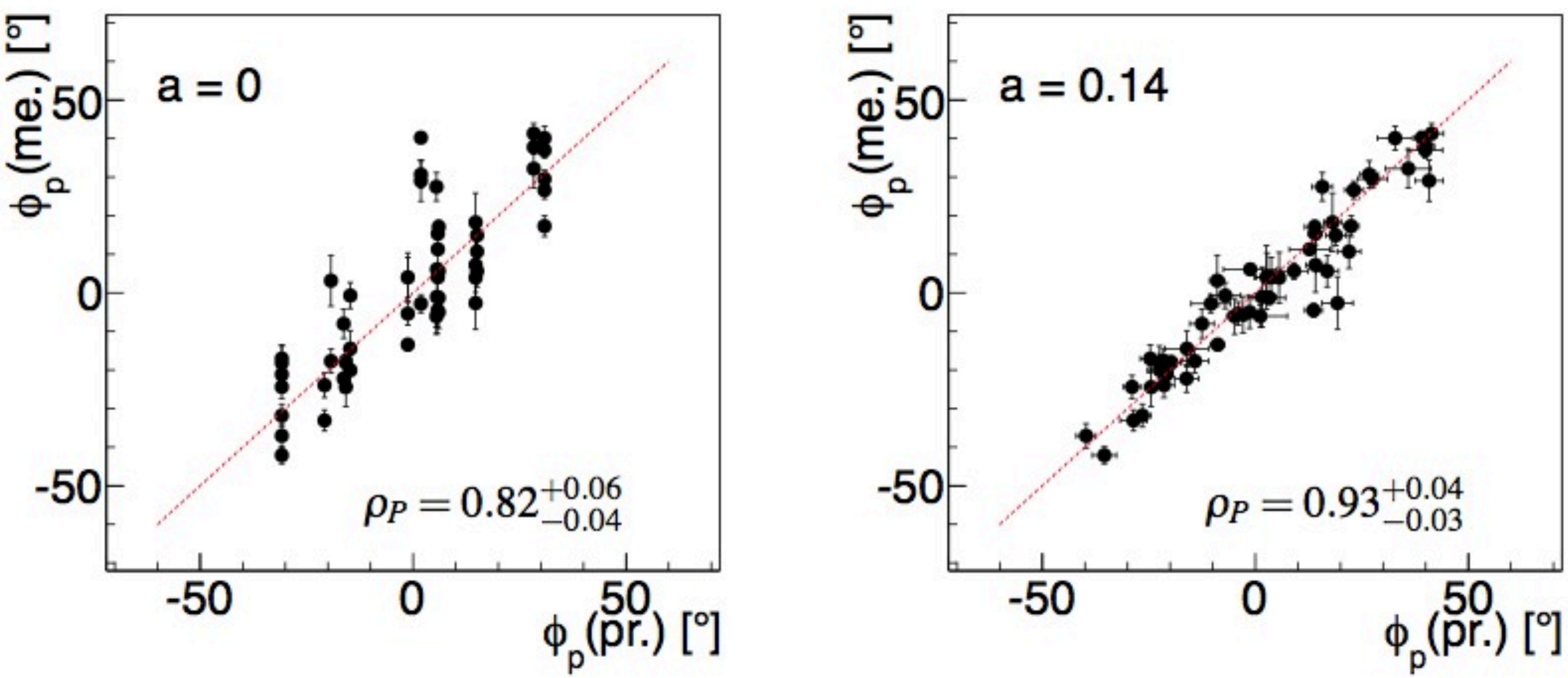
Auger ICRC 2013: arXiv:1307.5059

Auger + TA: arXiv:1310.0647

backup slides

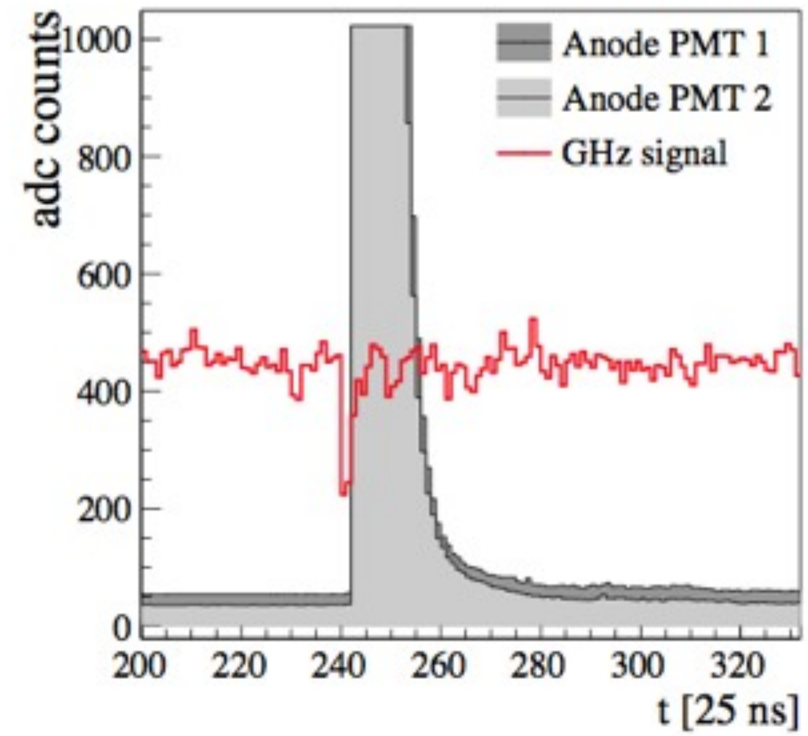
Radio emission with the Auger Engineering Array

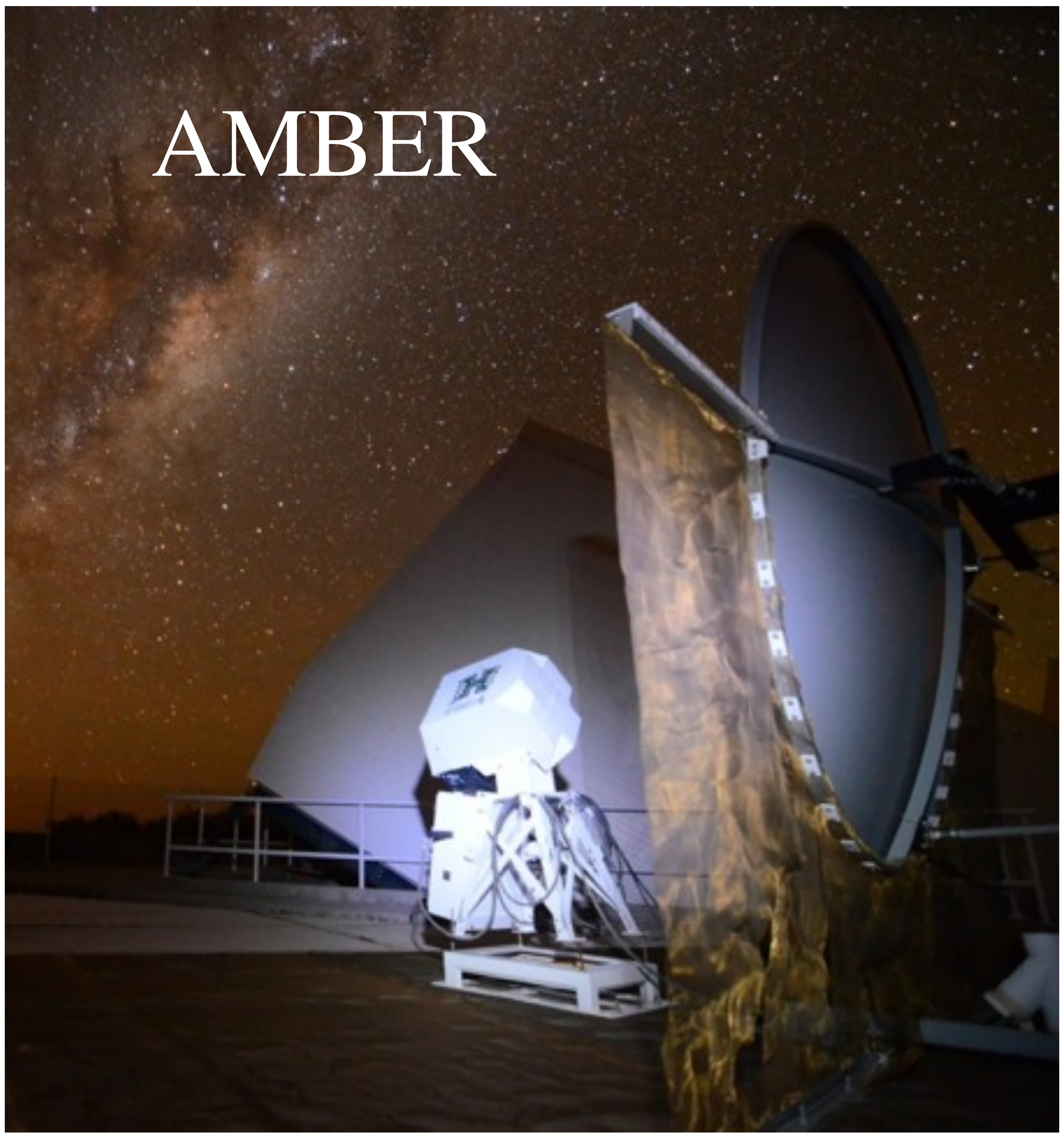
Polarization angle as a probe of the emission mechanism



GHz radio detection of Air Showers

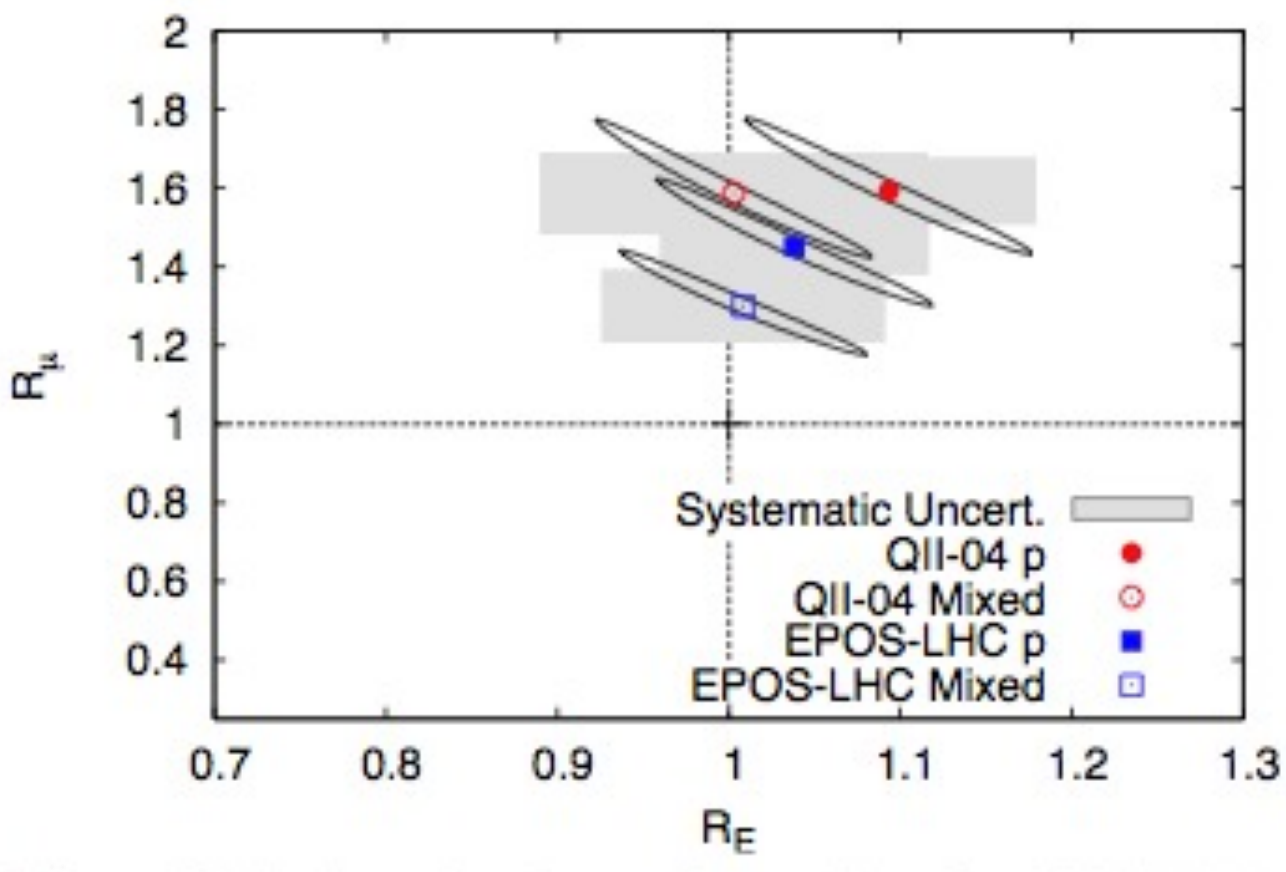
EASIER signal



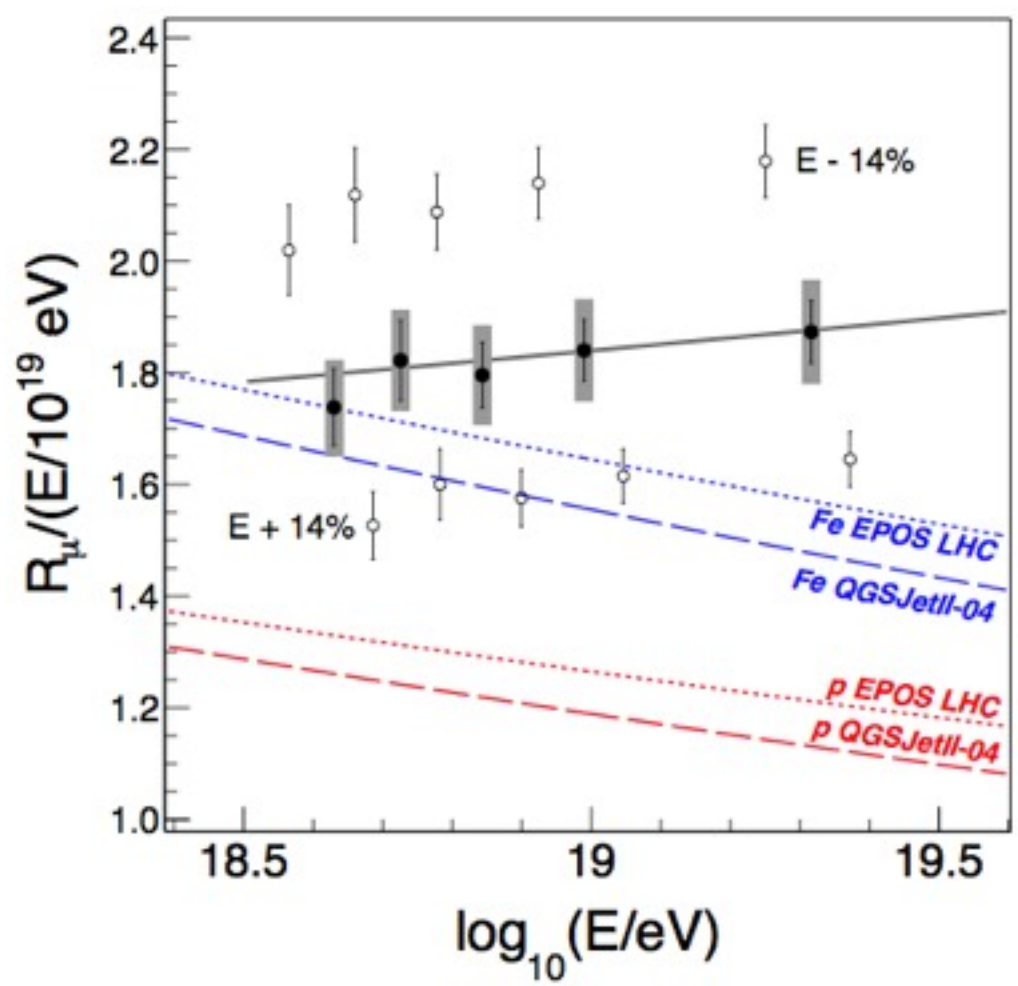


Hadronic interaction models and number of muons

Hybrid data 10^{19}eV



Inclined showers



SD PMT time series analysis:

$$\frac{f_\mu(\text{meas.})}{f_\mu(\text{sim})} = 1.33 \pm 0.02(\text{stat.}) \pm 0.05(\text{sys.})$$

(p - QGSjetII-04)

SUMMARY

- AUGER PROVIDES A WEALTH OF HIGH QUALITY DATA
- WE OBSERVE A COHERENT BEHAVIOR OF OBSERVABLES