Universität Hamburg
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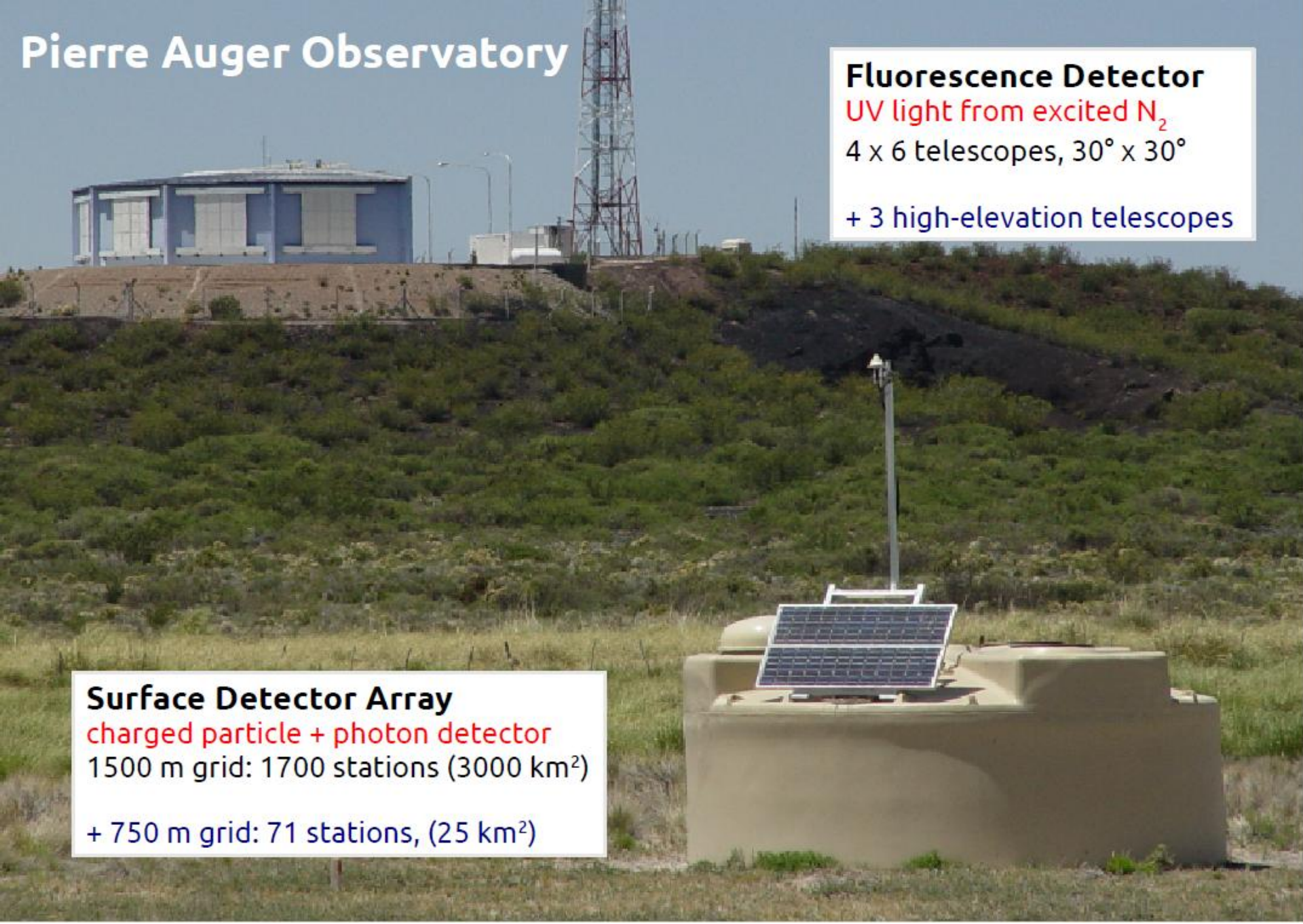
bmb+f - Förderschwerpunkt
Astroteilchenphysik
Großgeräte der physikalischen Grundlagenforschung

PIERRE AUGER OBSERVATORY

Current Results from the Pierre Auger Observatory

Arjen van Vliet for the Pierre Auger Collaboration

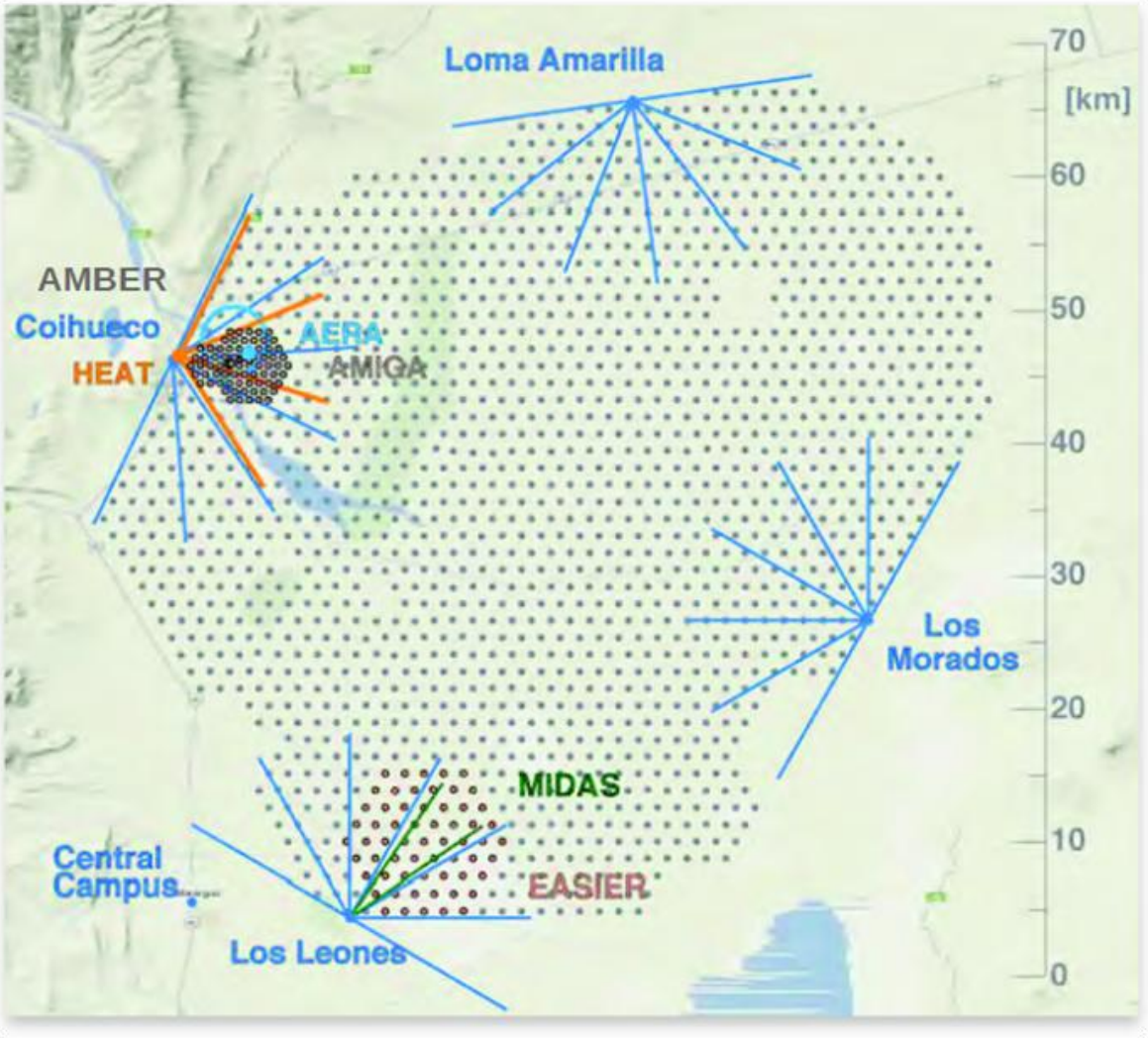
2013 PASCOS
19th International Symposium on Particles, Strings and Cosmology


Pierre Auger Observatory
Fluorescence Detector
UV light from excited N_2
4 x 6 telescopes, 30° x 30°
+ 3 high-elevation telescopes
Surface Detector Array
charged particle + photon detector
1500 m grid: 1700 stations (3000 km²)
+ 750 m grid: 71 stations, (25 km²)

Pierre Auger Observatory

Observatory for cosmic rays
- FD + HEAT
- SD + Infill

Laboratory for new technologies
- AMIGA μ-detection
- AERA MHz
- MIDAS GHz
- AMBER GHz
- EASIER MHz, GHz



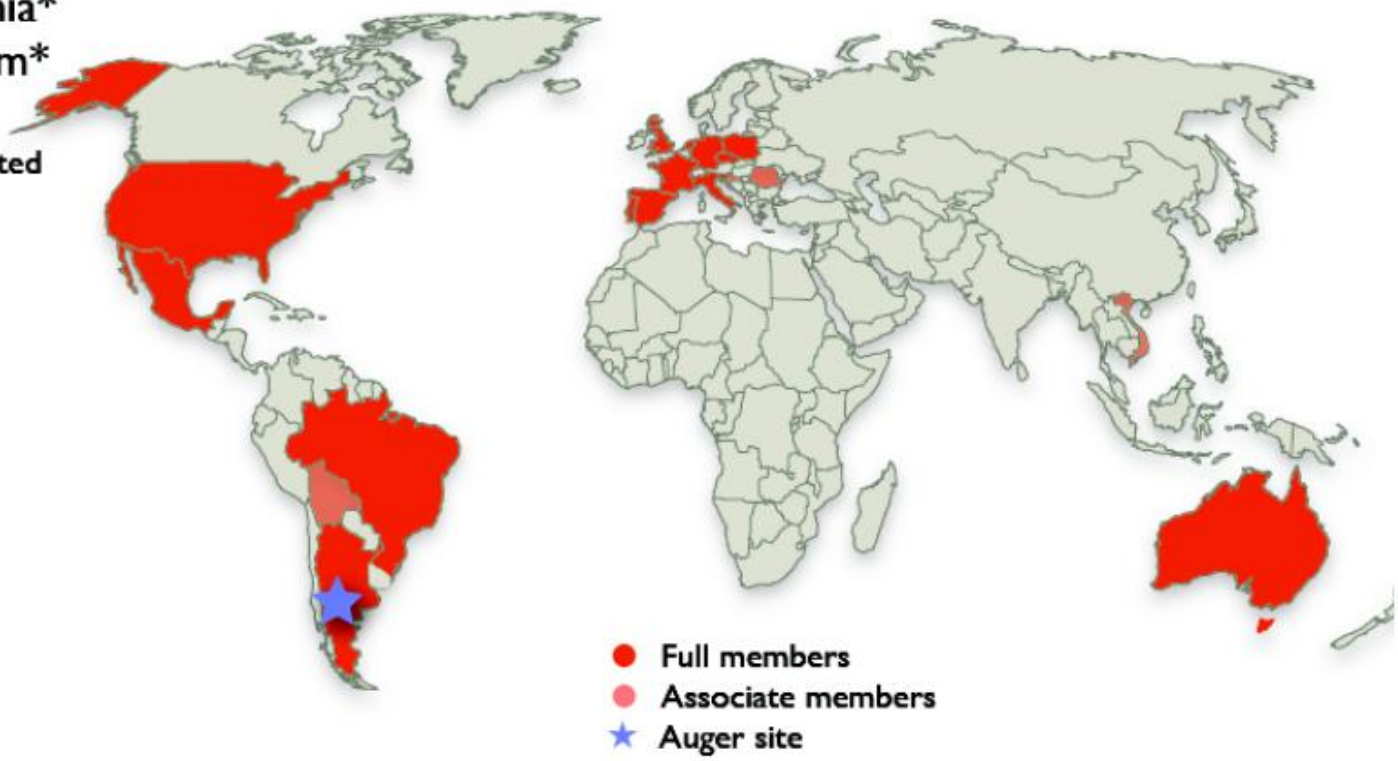
Pierre Auger Collaboration

About 500 members from 19 countries

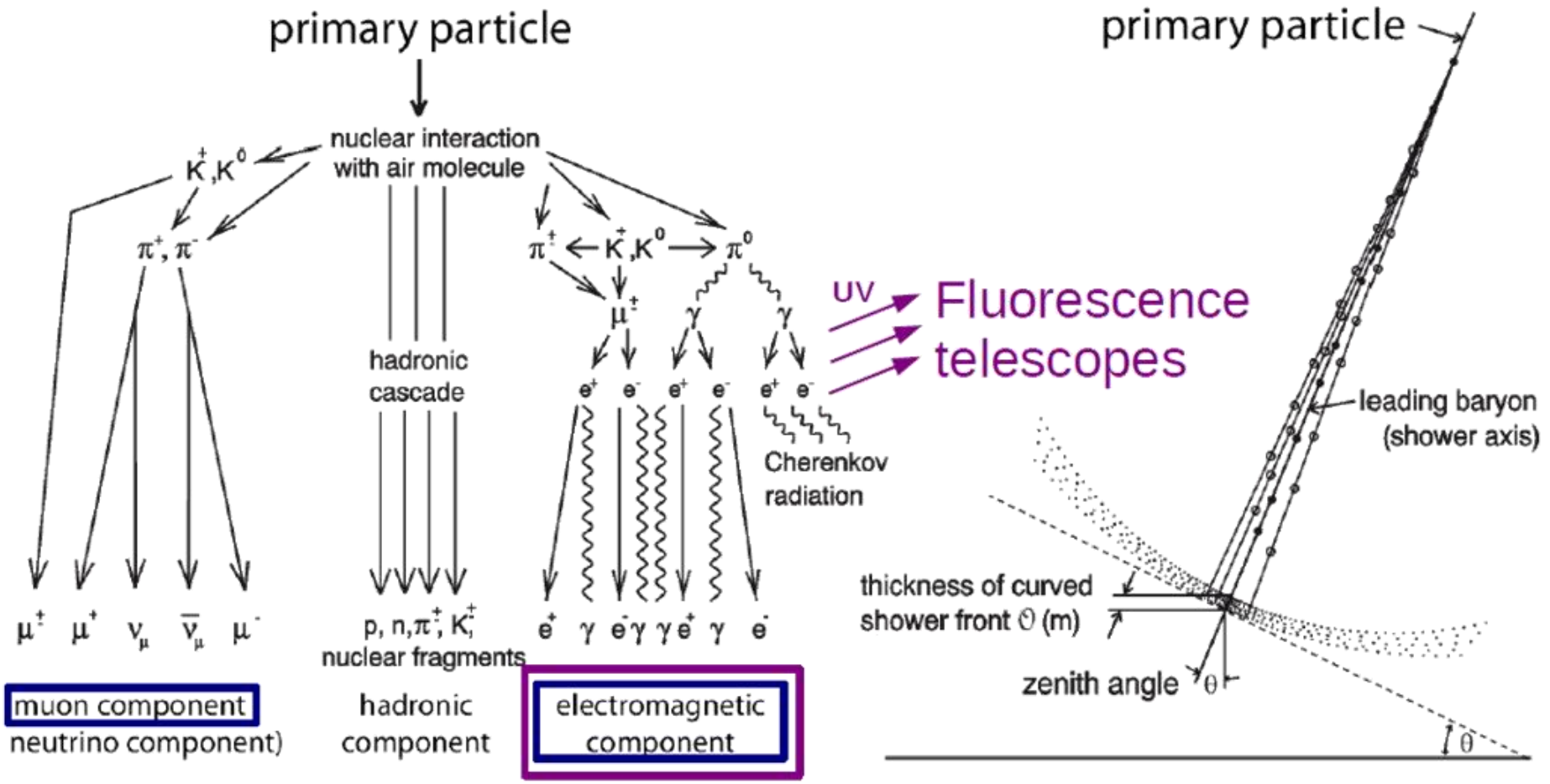
Argentina
Australia
Brazil
Croatia
Czech Republic
France
Germany
Italy
Mexico
Netherlands
Poland
Portugal
Slovenia
Spain
United Kingdom
USA

Bolivia*
Romania*
Vietnam*

*Associated



Extensive Air Showers



Surface Detector Array

Results shown at the ICRC 2013

- Update on Energy Scale
- Update on Cosmic Ray Flux
- Update on Xmax
- Update on Large Scale Anisotropy
- Muon Fraction
- Muon Production Depth
- Signal Rescaling
- AERA: MHz Emission Process
- Update on Neutrino Limit
- Measurement of Invisible Energy
- EASIER: First GHz Events
- Directional Photon Search
- Octocopter FD-Calibration
- Elves
- Search for Galactic Neutrons
- Search for Point Sources

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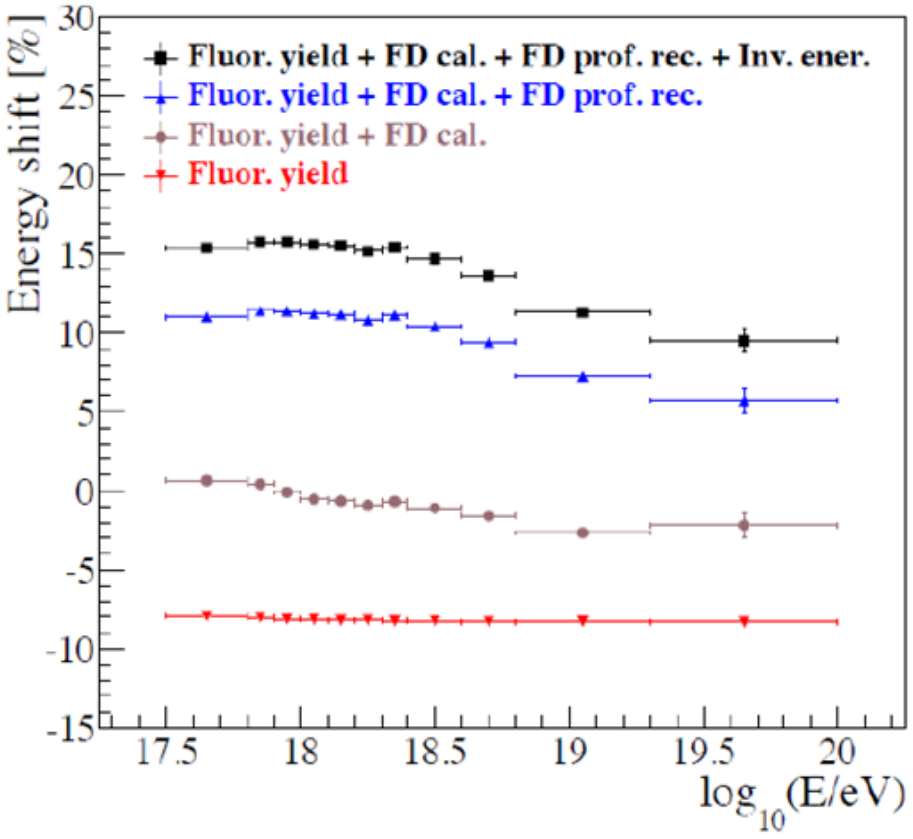
Update of Energy Scale



V. Verzi, ICRC 2013

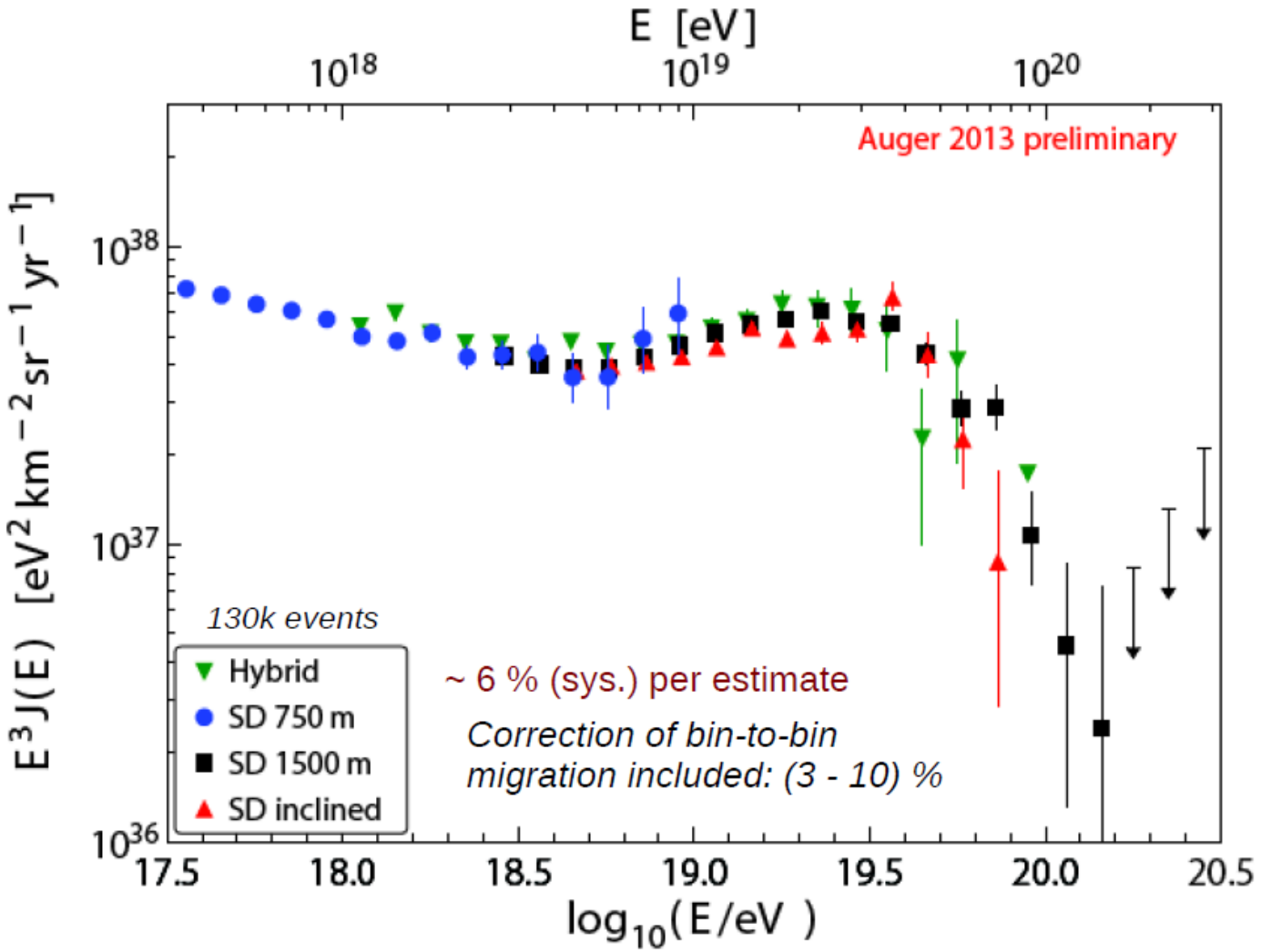
Systematic uncertainties

Fluorescence yield	3.6 %	14 %
Atmosphere	(3.4 – 6.2) %	8 %
FD calibration	9.9 %	10 %
FD profile rec.	(6.5 – 5.6) %	10 %
Invisible energy	(3 – 1.5) %	4 %
Time stability	5 %	
Total	14 %	22 %

*Systematic uncertainty reduced from **22 %** to **14 %***

Cosmic Ray Flux

A. Schulz, D. Ravignani
ICRC 2013



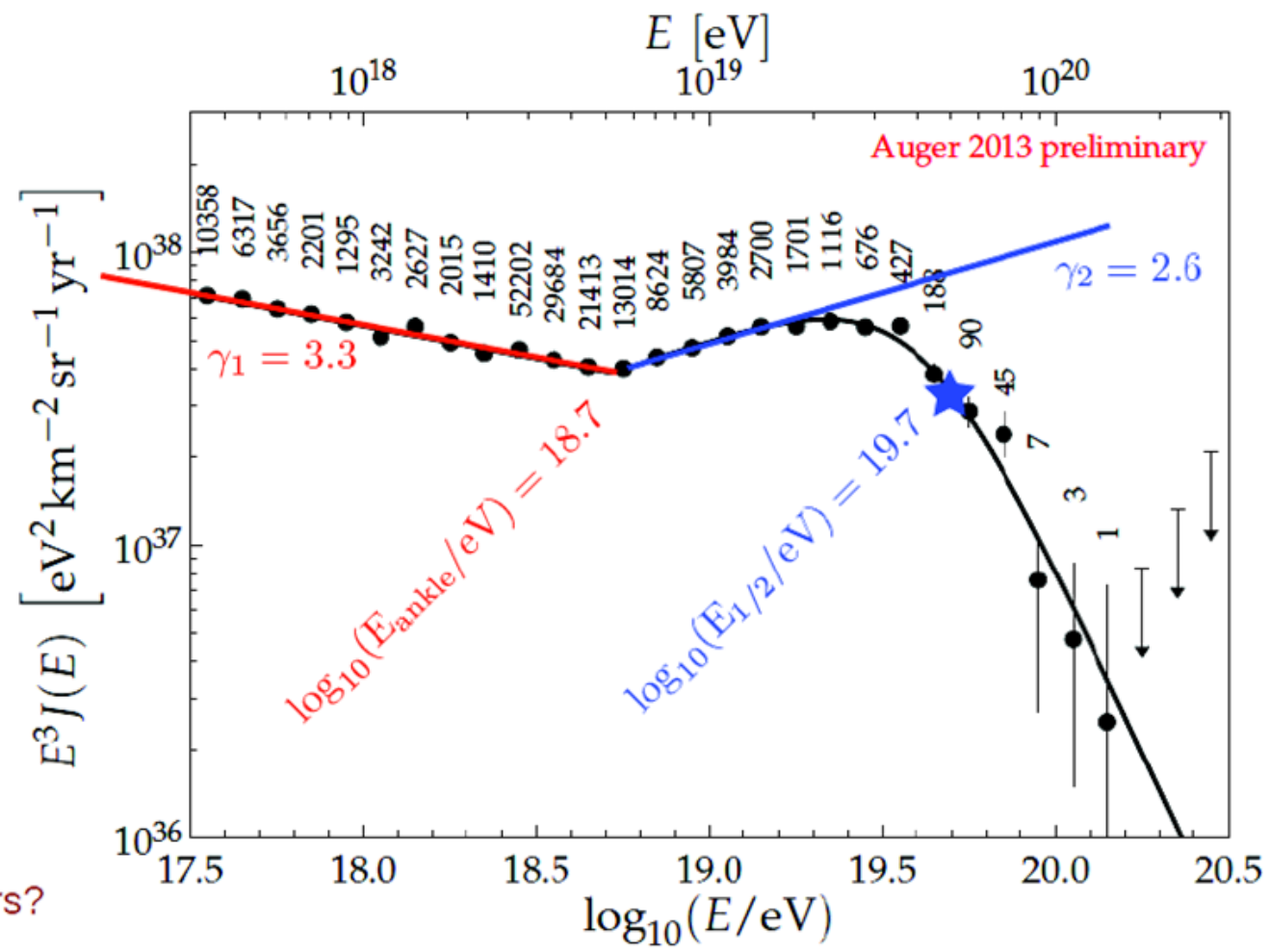
Cosmic Ray Flux

A. Schulz, D. Ravignani
ICRC 2013

Bin-wise combination, weighted according to statistical and systematic uncertainties

flux shifts

- Hybrid -6%,
- Inclined +4%,
- 750 m array +2%,
- 1500 m -1%



Sharp ankle

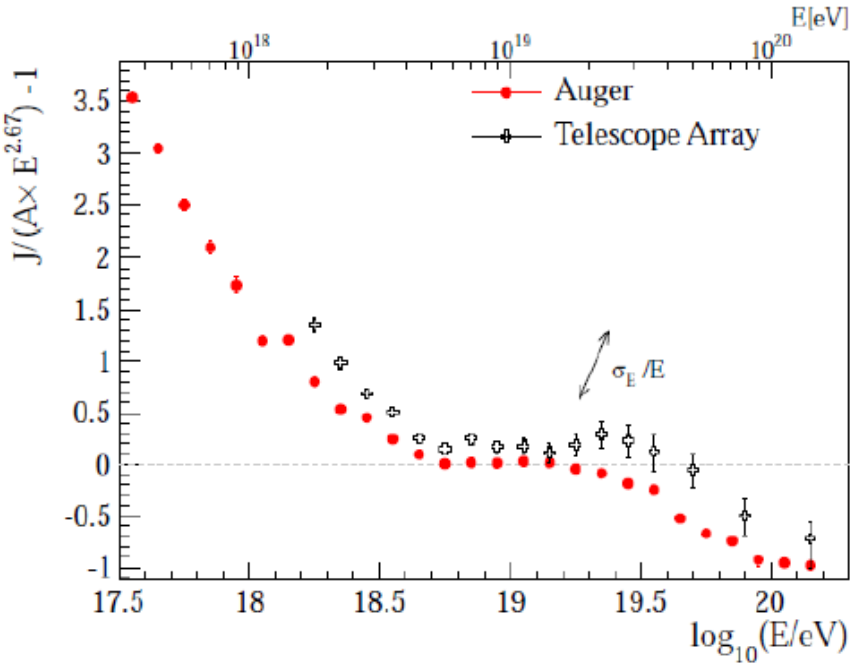
Flux suppression

- GZK cut-off?
- End of accelerators?

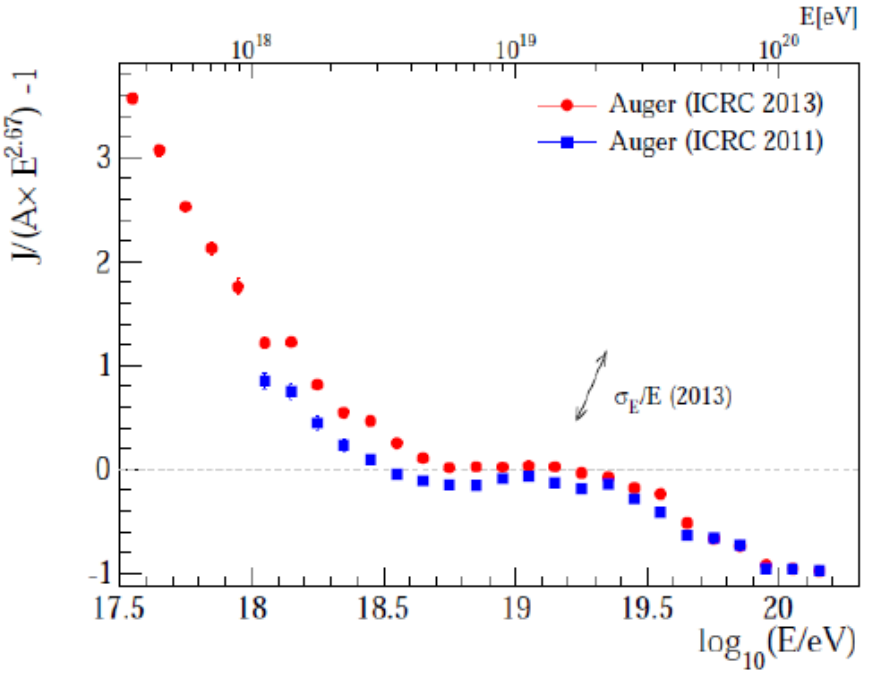
Cosmic Ray Flux

A. Schulz, D. Ravignani
ICRC 2013

Updated energy scale reduced offset to flux measured by Telescope Array

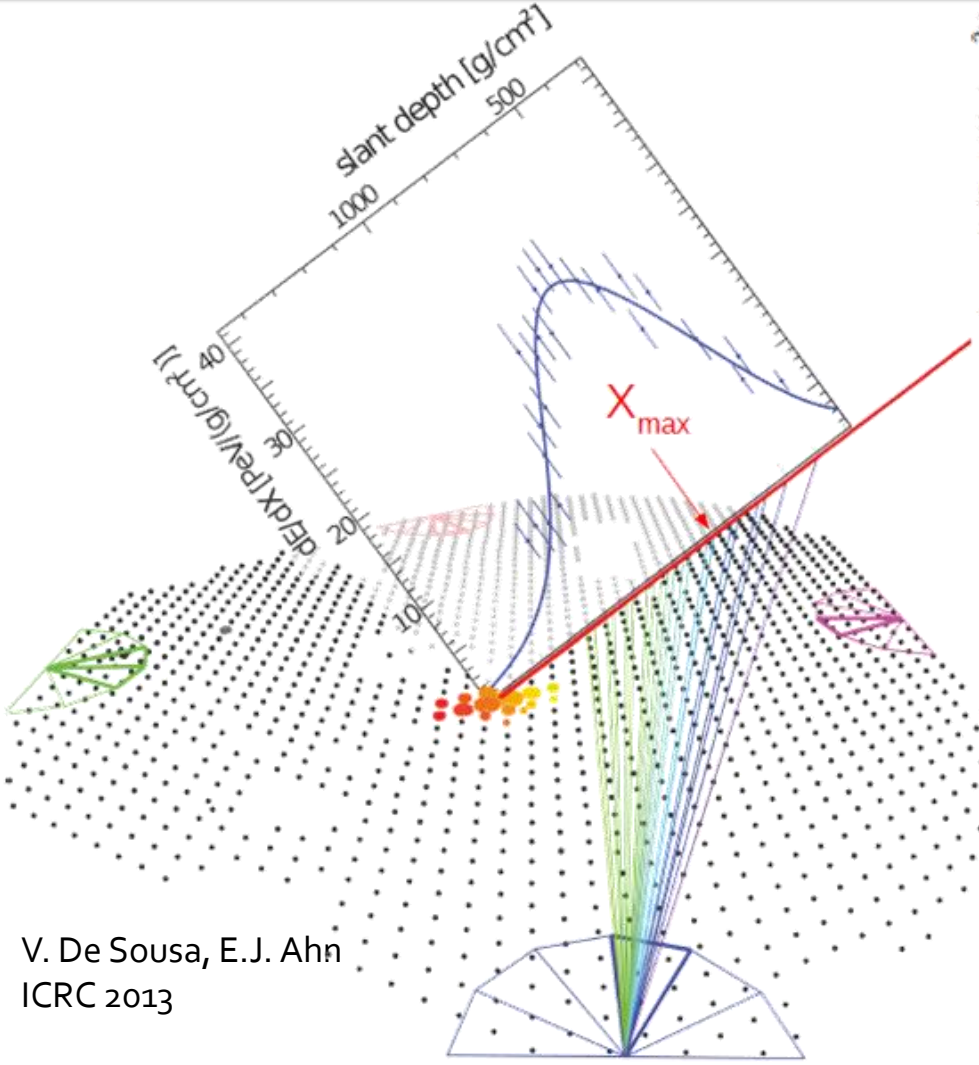


(Telescope array: T. Abu-Zayyad et al., ApJ 768 (2013) L1.)

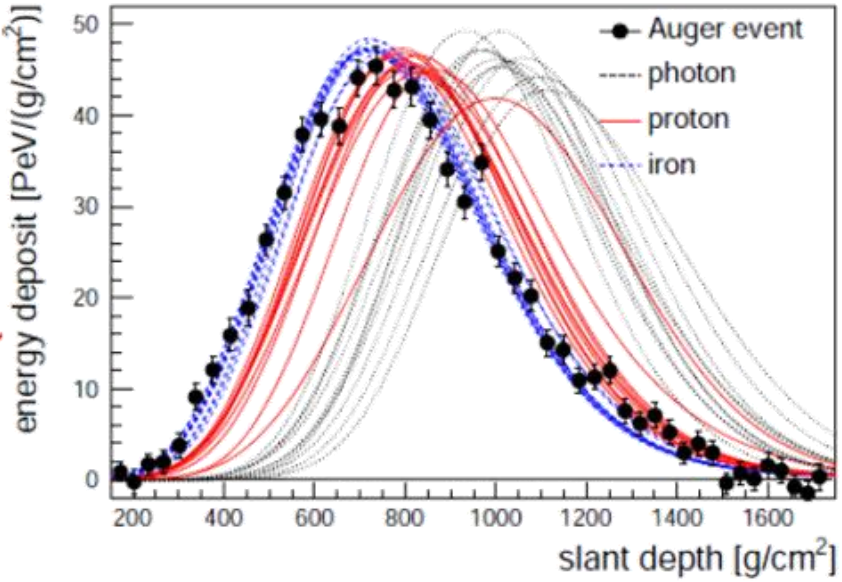


ICRC 2013 result agrees with ICRC 2011 and TA within systematic uncertainties

Depth of Shower Maximum



V. De Sousa, E.J. Ahn
ICRC 2013



photons protons iron

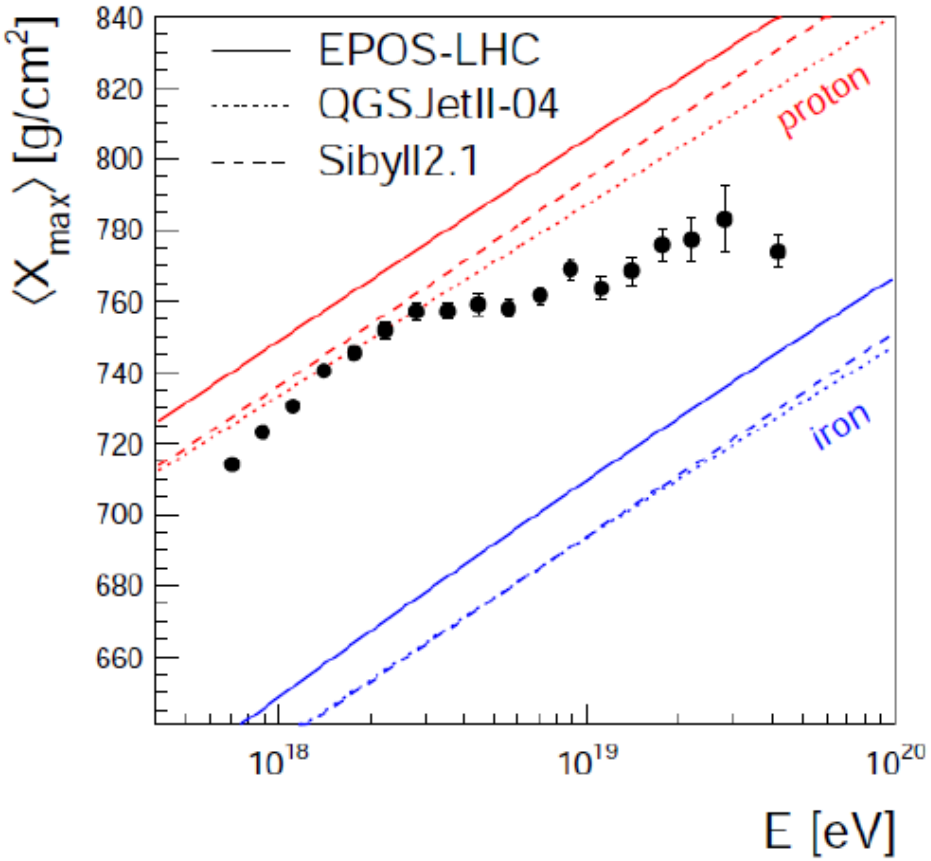
depth of shower

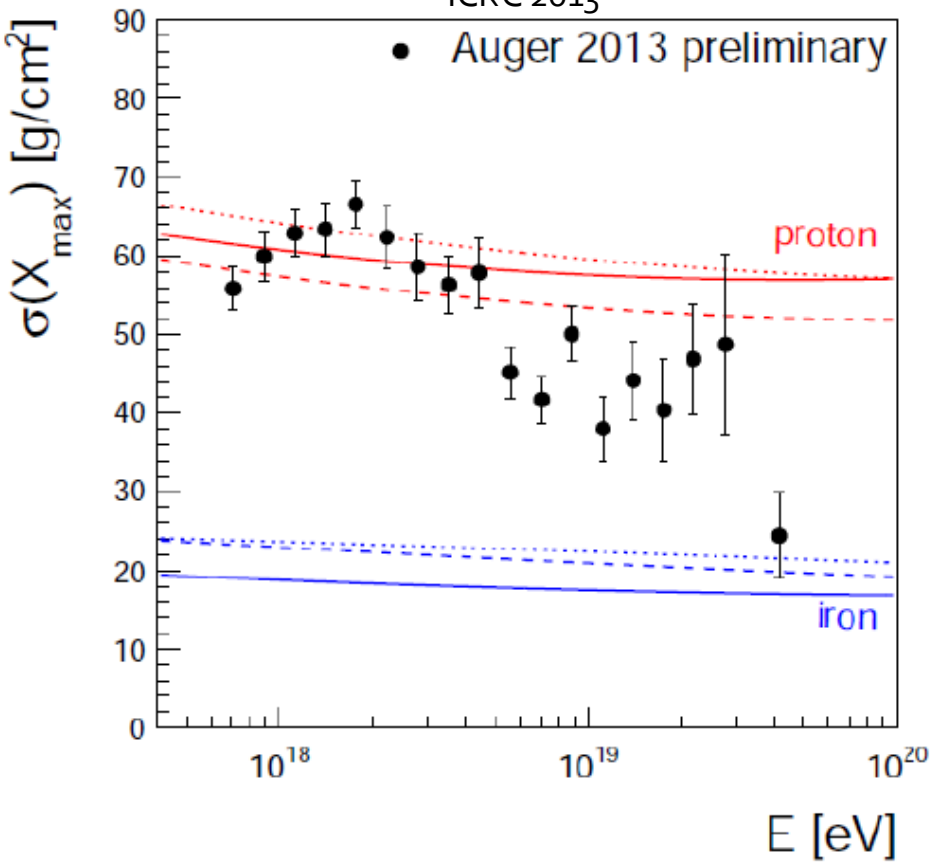
fluctuations

muon number

Composition

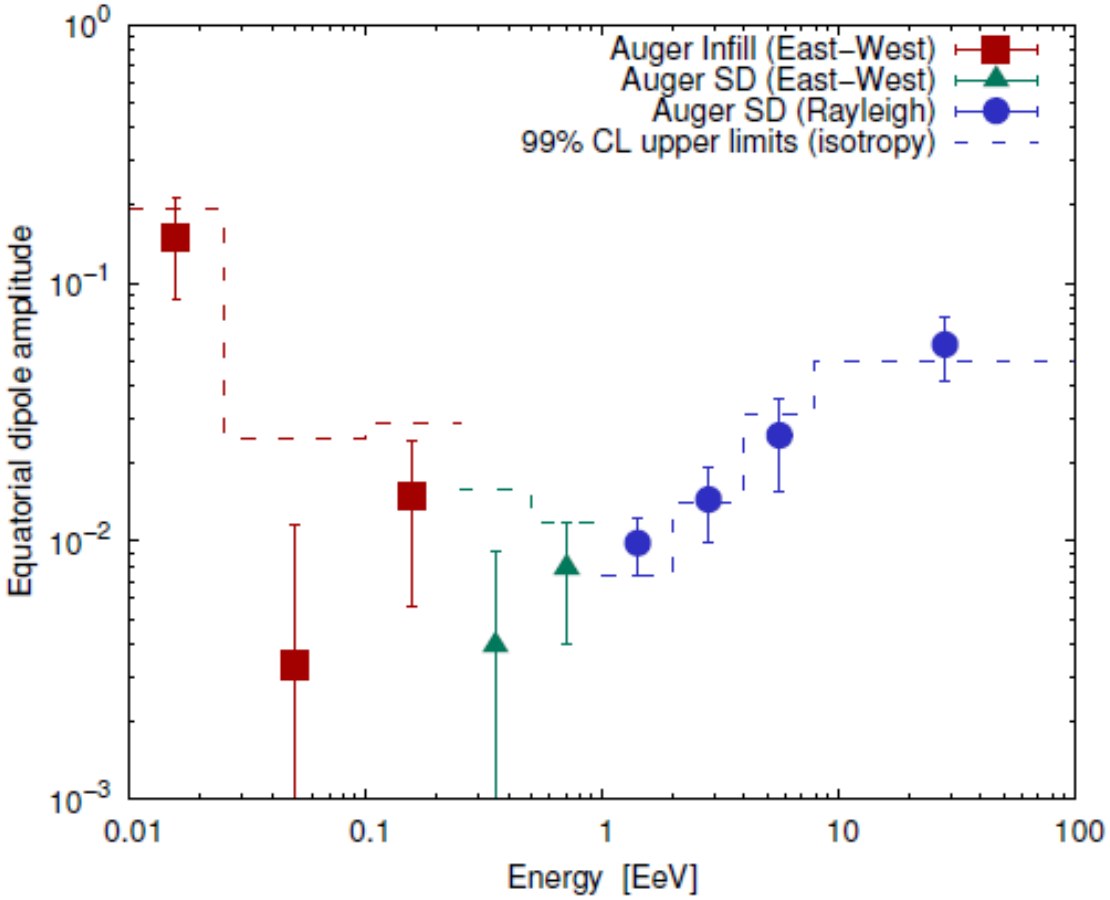
V. De Sousa, E.J. Ahn
ICRC 2013





Heavy composition at highest energies:
Opens possibility that suppression is due to end of accelerators

Search for Large Scale Anisotropy

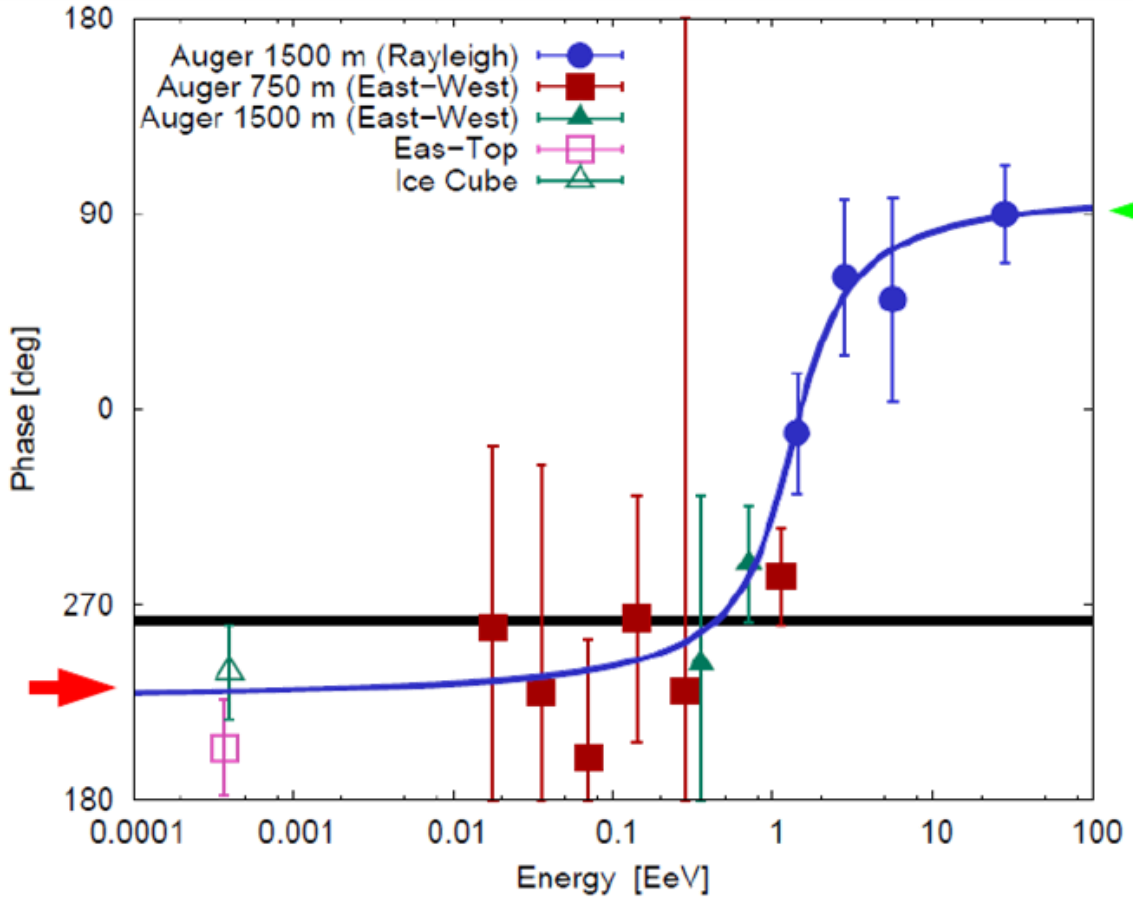


Hints for dipole in data

- Amplitude not significant...

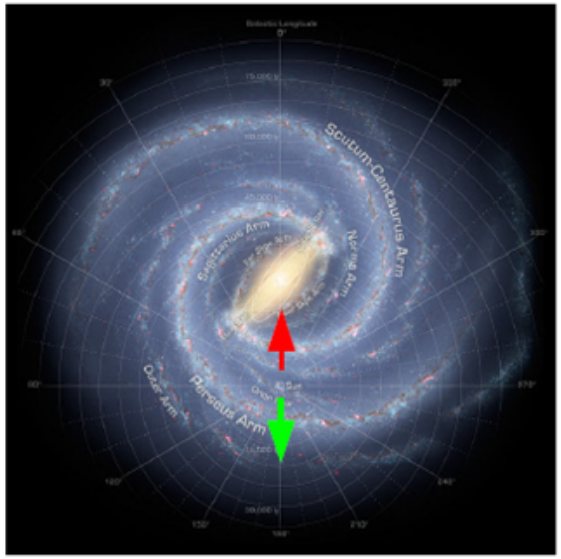
I. Sidelnik, R. de Almeida
ICRC 2013

Search for Large Scale Anisotropy



Hints for dipole in data

- Amplitude not significant...
- ...yet phase shows interesting transition



I. Sidelnik, R. de Almeida
ICRC 2013

Eas-Top: M. Aglietta *et al.* 2009 ApJ **692** L130
IceCube: R. Abbasi *et al.* 2012 ApJ **746** 33

Hadronic Interactions

- Reliable knowledge of energy allows detailed studies of hadronic interactions
- Auger measured:

$$\sigma_{inel}(pp) = 92 \pm 7(stat)^{+9}_{-11}(syst) \pm 7(Glauber)\ \mathrm{mb}$$

at center-of-mass energy equivalent to

$$57 \pm 0.3(stat) \pm 6(syst)\ \mathrm{TeV}$$

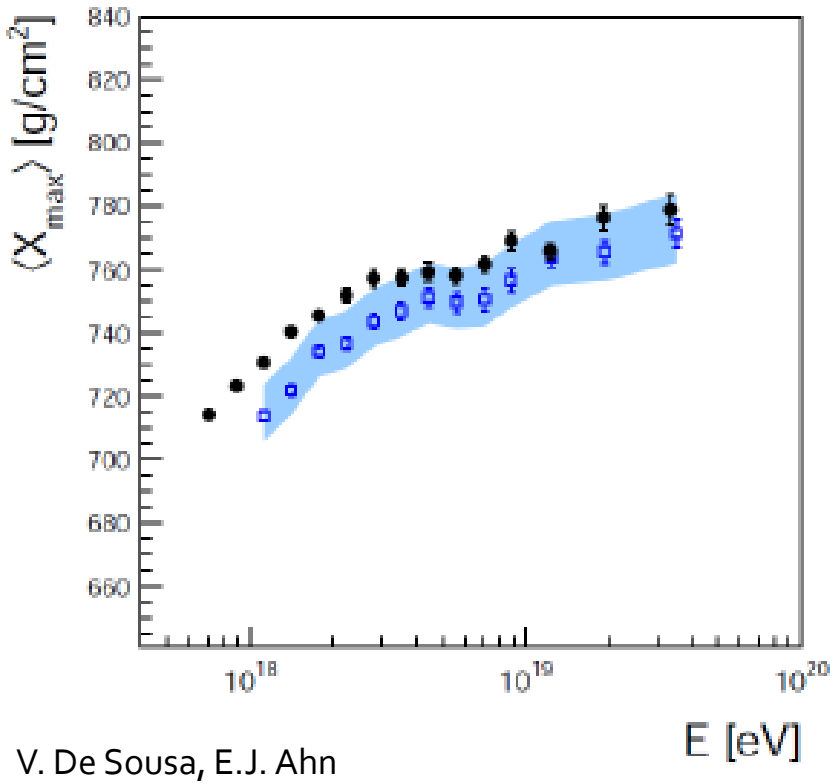
Conclusions

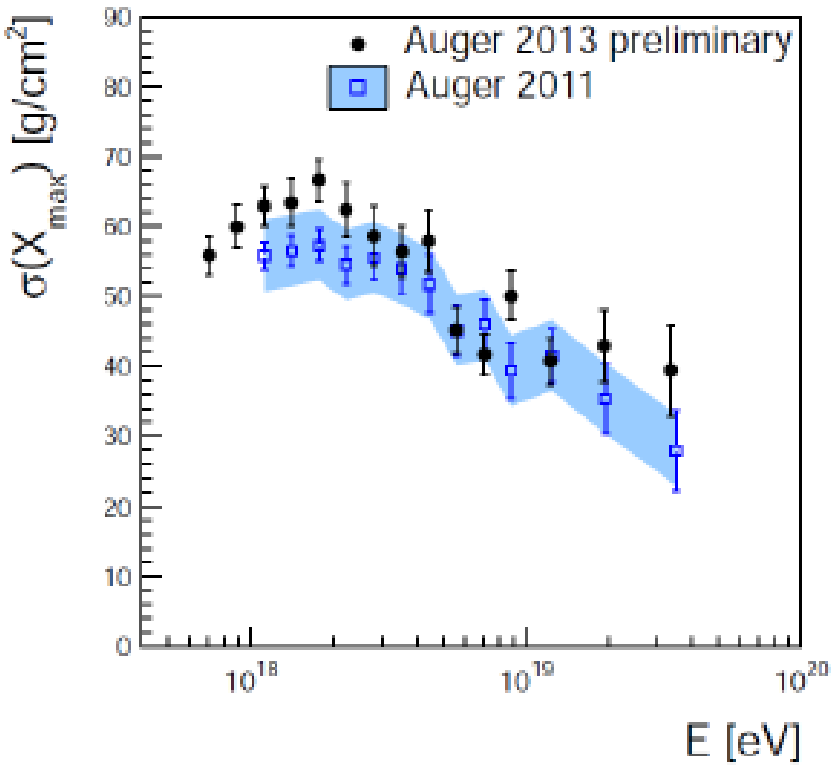
- Auger Observatory is producing measurements of the UHECR properties over 4 orders of magnitude in energy
- Spectrum: clear indication of sharp ankle and flux suppression
- Composition: indication for increasing mass with energy above $E \approx 3$ EeV
- Anisotropy: hints for dipole in the data

Backup Slides

Composition

$\langle X_{max} \rangle$: individual shifts within their systematic uncertainties, but all in same direction...





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$\sigma(X_{max})$: acceptance correction caused biggest shift

Large Scale Anisotropy

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Large scale anisotropy studies

- Help to understand the nature and the origin of cosmic rays together with energy spectrum and mass composition
- Transition from a galactic to an extragalactic origin should induce a significant change in the large scale angular distribution of cosmic rays

Analysis of data from the Pierre Auger Observatory

- Study of the large scale distribution of arrival directions of cosmic rays based on the first harmonic analysis in right ascension
- Data: January 1 2004 - December 31 2012 data
- Energy range: from 10^{16} eV to more than 10^{19} eV
- Accesible thanks to the joint data of the regular Auger SD and its enhancement: the Infill array

Large Scale Anisotropy

First harmonic modulations are small:

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ICRC 2013

- Account for spurious modulations (experimental and atmospheric)
- Use methods which are not sensitive to these effects

Modified Rayleigh (E>1 EeV):

- Energy assignment accounting for weather and geomagnetic effects
- Fourier coefficients $a = \frac{2}{N}\sum_{i=1}^{N} w_i \cos(\alpha_i)$, $b = \frac{2}{N}\sum_{i=1}^{N} w_i \sin(\alpha_i)$, w_i accounting for the array growth, dead time and tilt of the array
- Amplitude $r = \sqrt{a^2 + b^2}$ and phase $\varphi = \arctan(b/a)$

East West method (E<1 EeV):

- $I_E(\alpha^0)$-$I_W(\alpha^0)$ allows us to remove systematic effects
- Reduced sensitivity

Large Scale Anisotropy

- r depends on the Observatory latitude and observed zenith angles
- To compare between experiments use the equatorial dipole component
  $d_\perp \simeq r / \langle \cos\delta \rangle$
- 3 bins above 1 EeV have low probability to arise from isotropy
  P(1-2 EeV)=0.03%
  P(2-4 EeV)=0.9%
  P(>8 EeV)=0.1%

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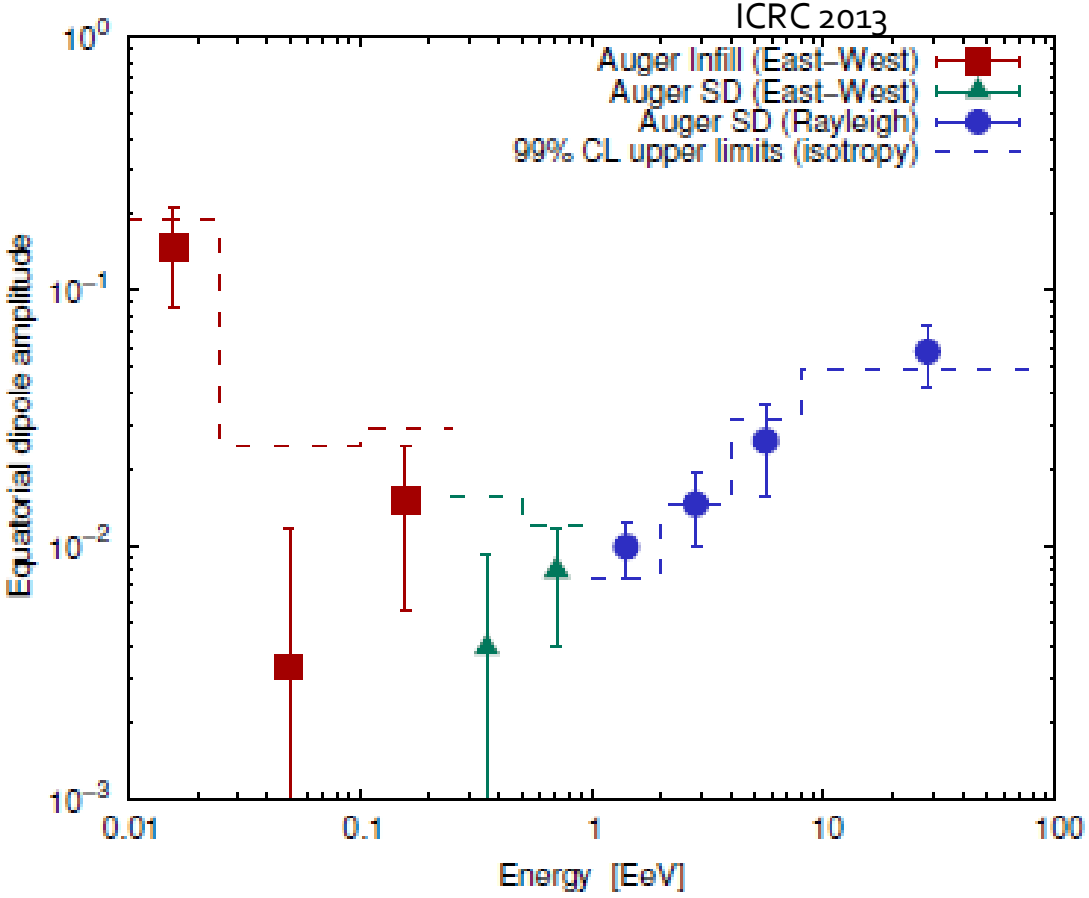
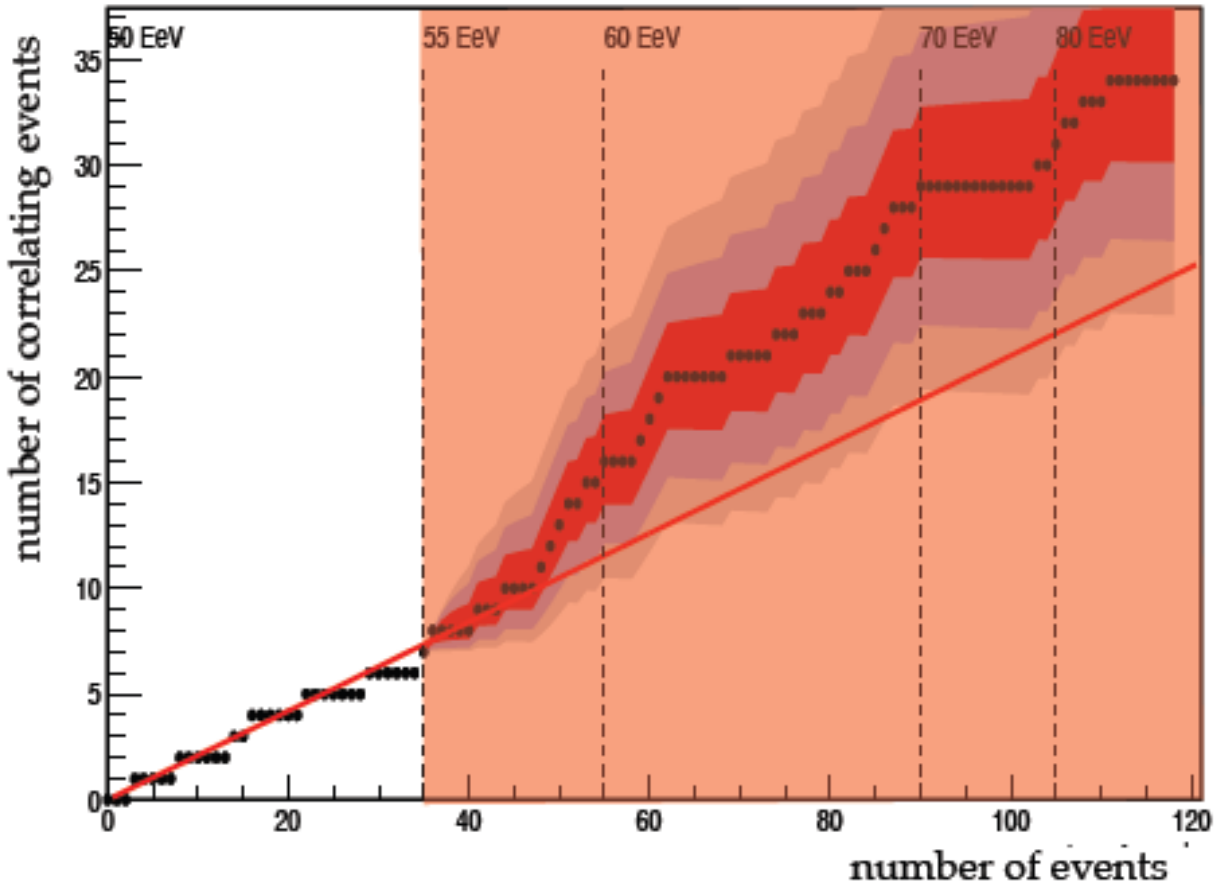


Amplitude of the dipole

Anisotropy, VCV Correlation



A. Letessier-Selvon, ICRC 2013

Radio News

T. Huege,
F. Schröder,
R. Gaior
ICRC 2013

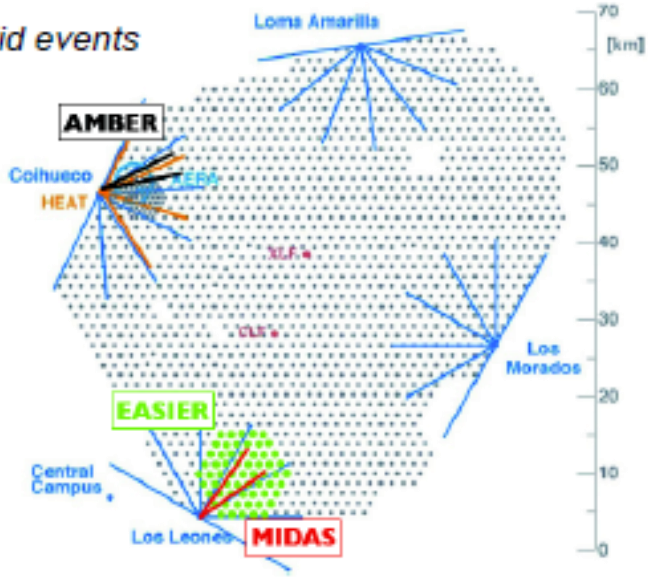
Ongoing R&D,
exploiting hybrid events

AERA (MHz)

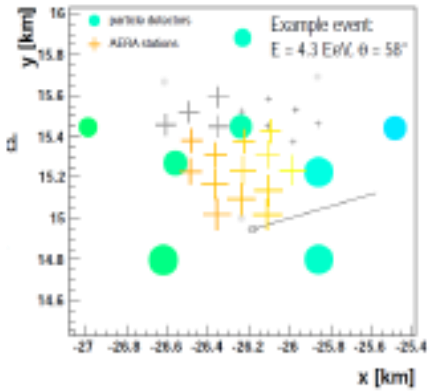
- 124 antenna stations, 6 km²
- 350 hybrid events with SD
- Two emission processes confirmed
  - 86 % geomagnetic effect
  - 14 % Askaryan effect

EASIER (MHz, GHz)

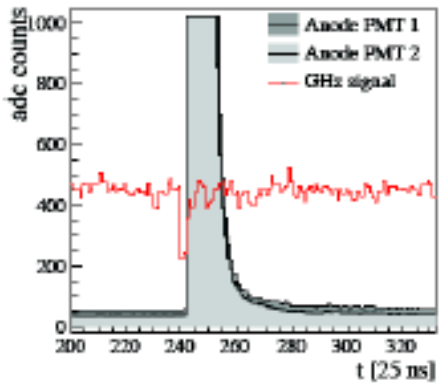
- 61 modified SD stations
- 2 years of data
- Three GHz events detected
- Emission process under investigation

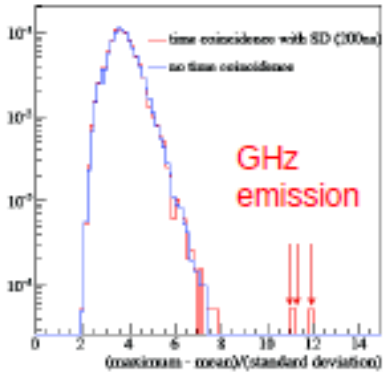


AERA MHz event



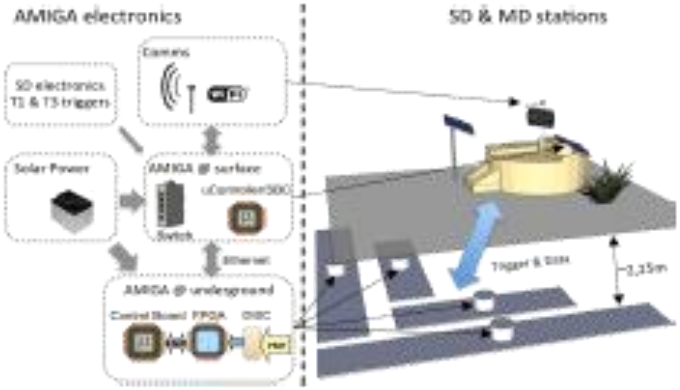
EASIER GHz event

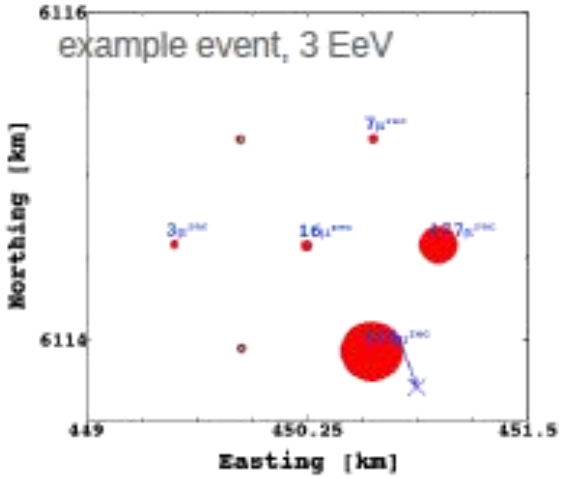


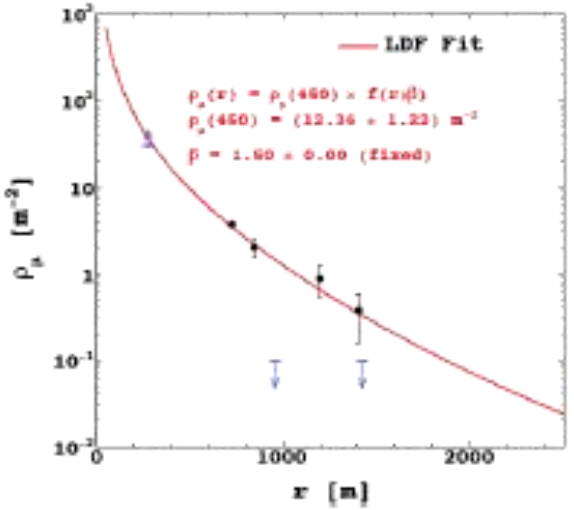


Muon Detectors: AMIGA

Status of unitary cell in 750 m grid







F. Suarez
ICRC 2013

Muon detectors will validate and extend SD-only muon estimation capabilities