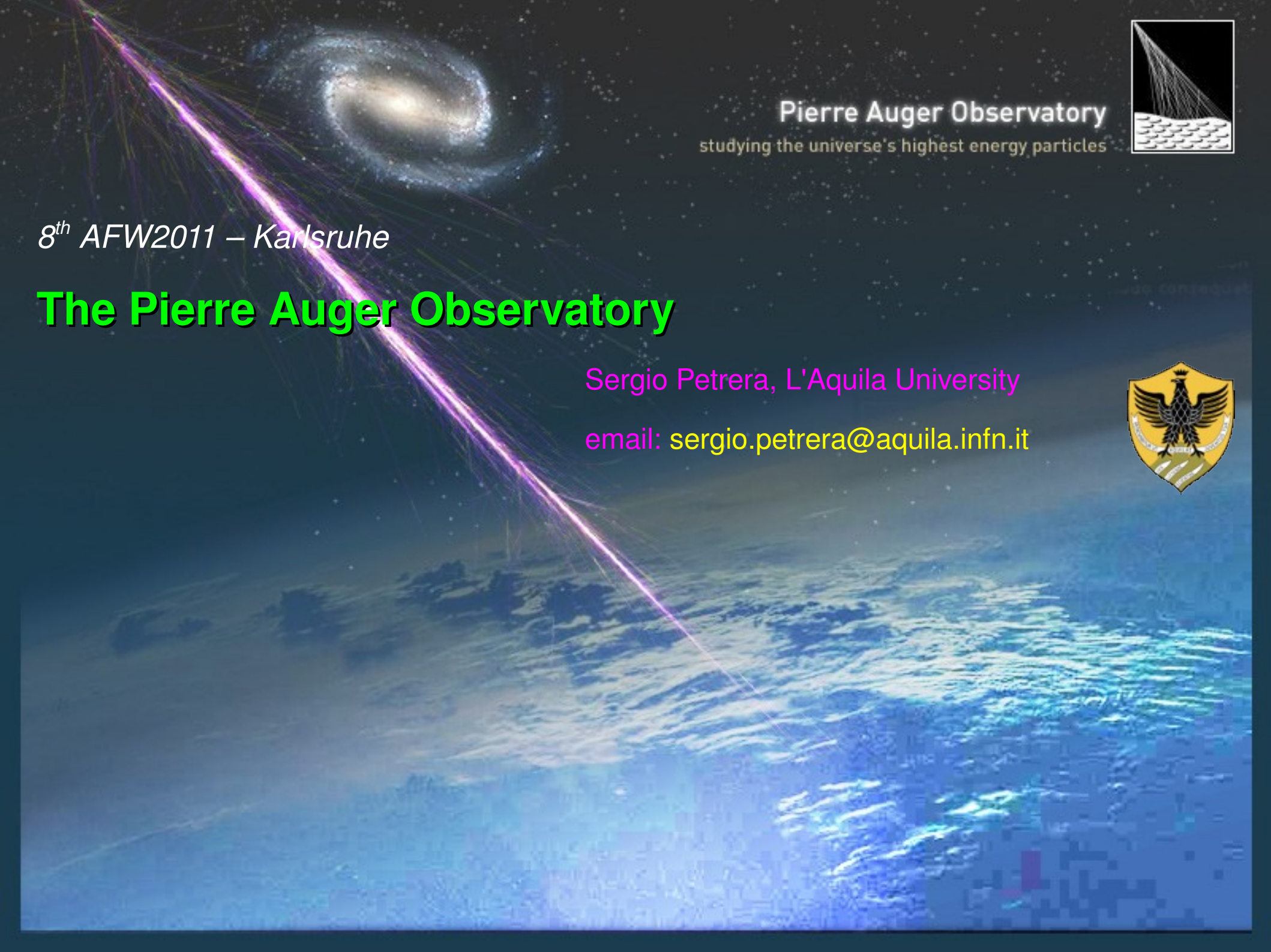


8th AFW2011 – Karlsruhe

The Pierre Auger Observatory

Sergio Petrera, L'Aquila University

email: sergio.petrera@aquila.infn.it

Pierre Auger Observatory

studying the universe's highest energy particles

8th AFW2011 – Karlsruhe

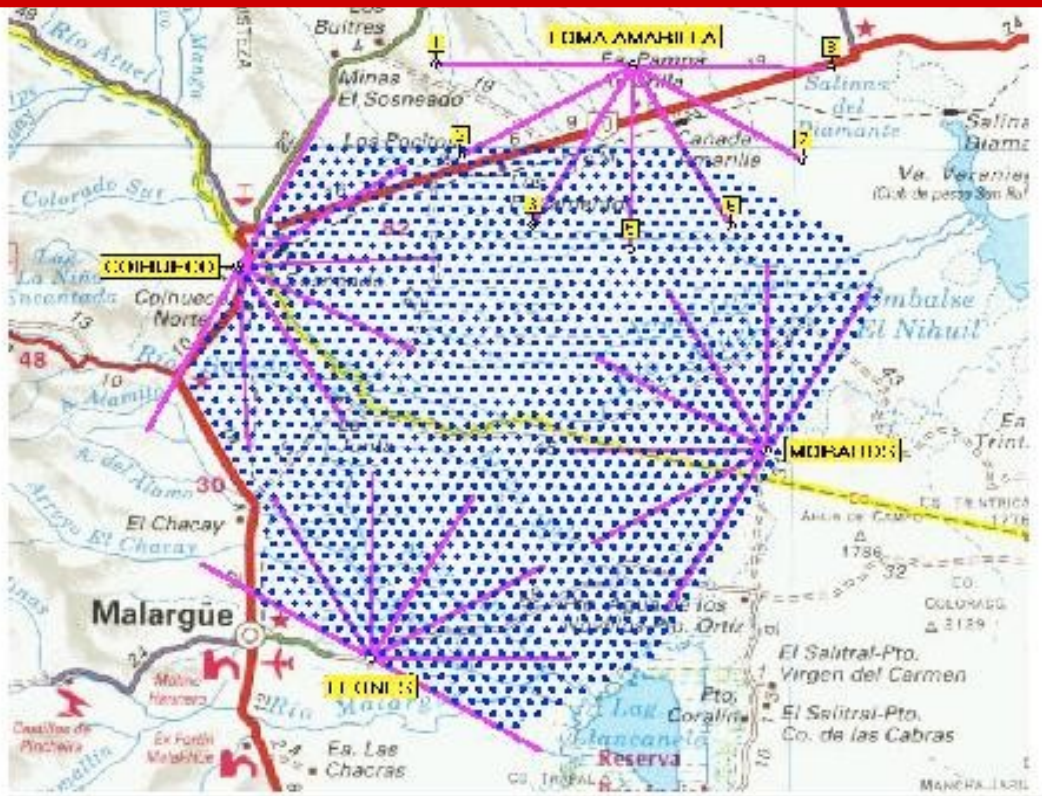
The Pierre Auger Observatory

Sergio Petrera, L'Aquila University

email: sergio.petrera@aquila.infn.it

- Fundamentals of Auger detection and analysis
- Present status of the Pierre Auger Observatory
- The physics items:
  - *energy spectrum*
  - *CR composition*
  - *arrival directions*
- Summary and outlook

Auger Observatory in Argentina



Surface Array
1600 detector stations
1.5 km spacing
3000 km²

Fluorescence Detectors
4 Telescope enclosures
6 Telescopes per enclosure
24 Telescopes total

~450 collaboration members in 19 countries

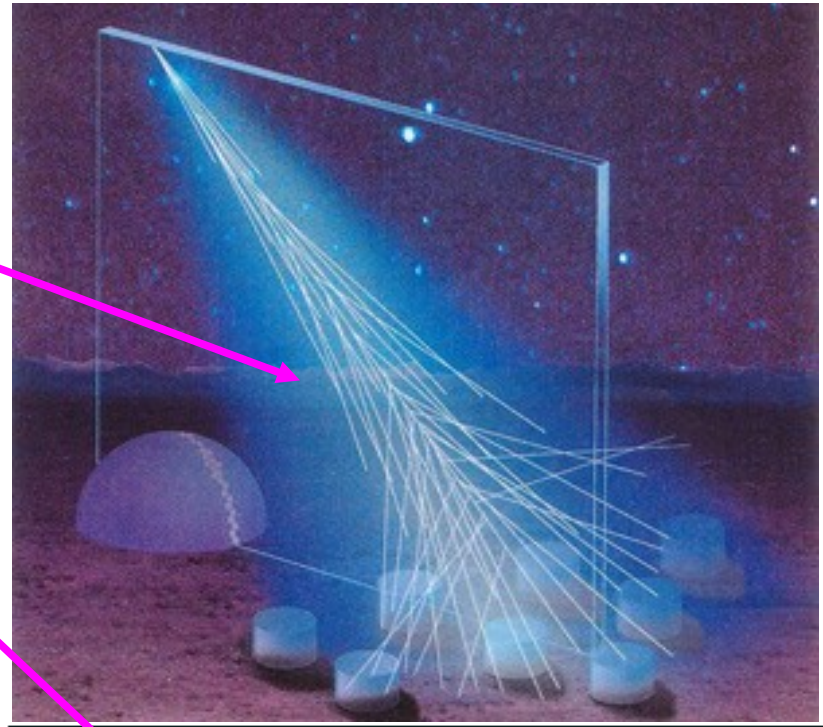
Auger detection techniques

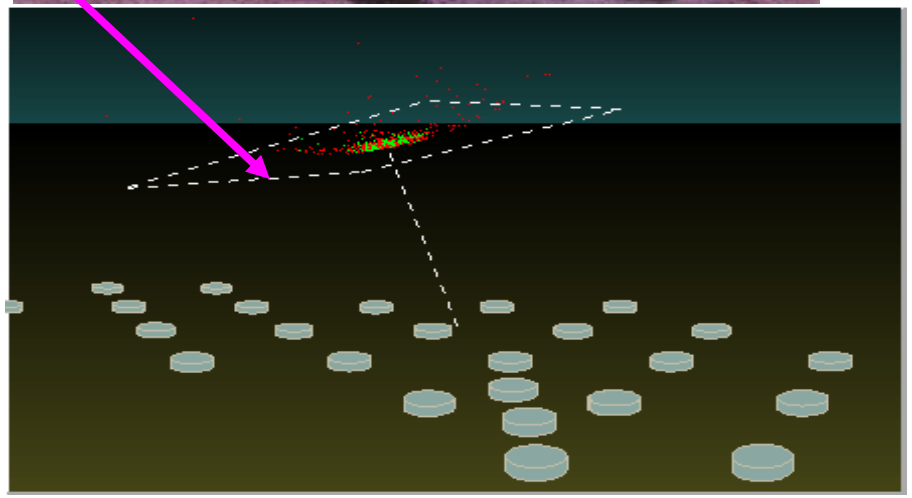
Nitrogen fluorescence detected as shower develops

Particles detected as they reach ground

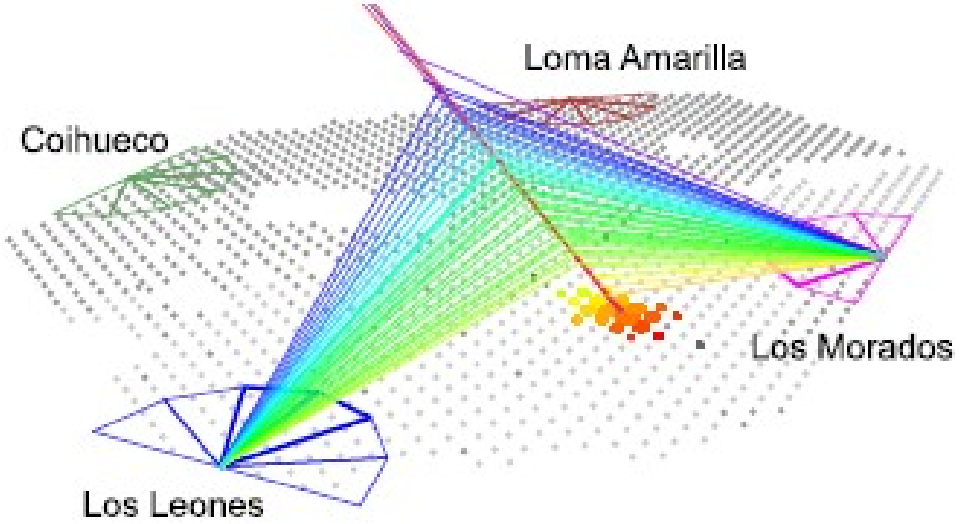
- Fluorescence (50 W light bulb @ c)
  - nearly calorimetric
  - direct view of shower evolution
  - 10% duty cycle
  - Acceptance depends on energy + atmosphere
- Surface (10^{12} particles over 20 km^2)
  - 100% duty cycle
  - Flat acceptance above threshold
  - Indirect measurements of primary energy and mass (relies on simulation)

Hybrid = surface + fluorescence





Observables at Auger



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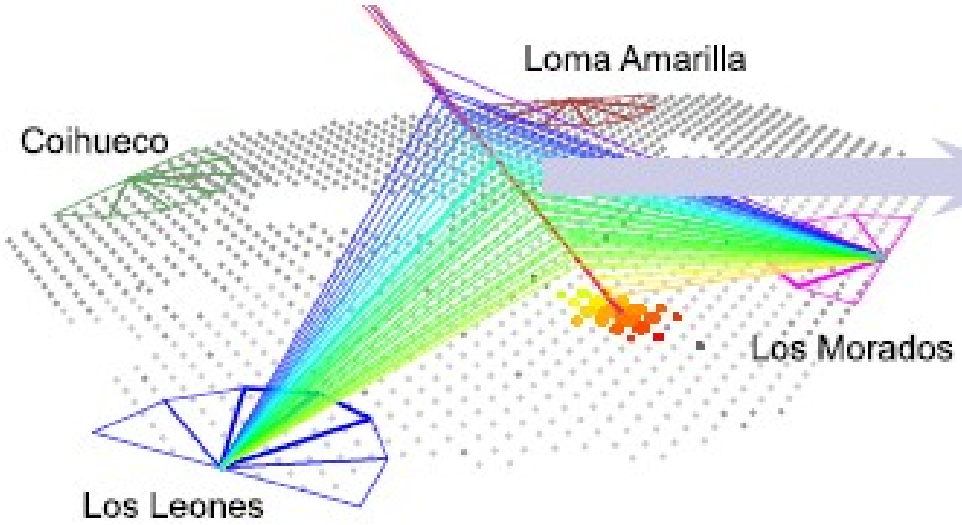
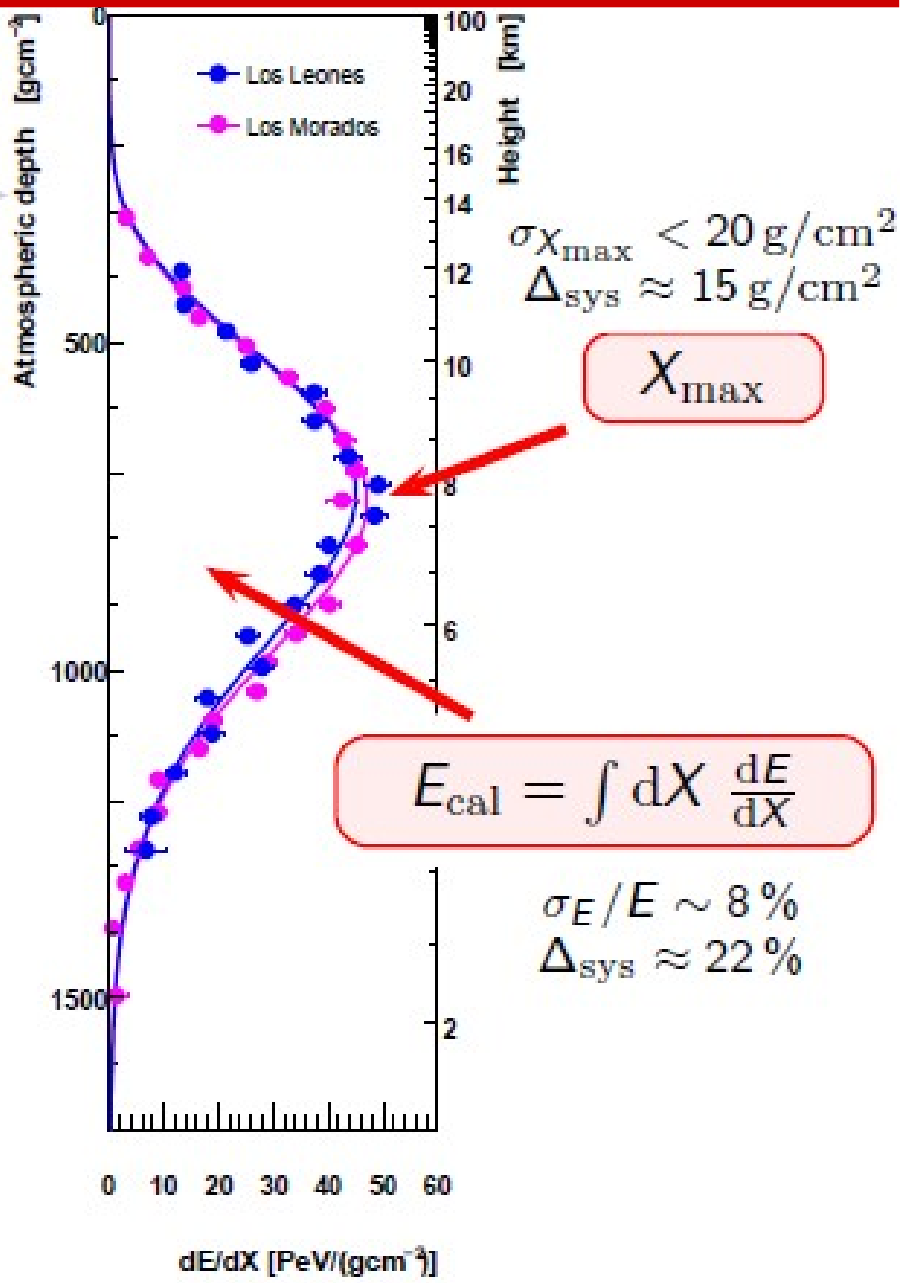




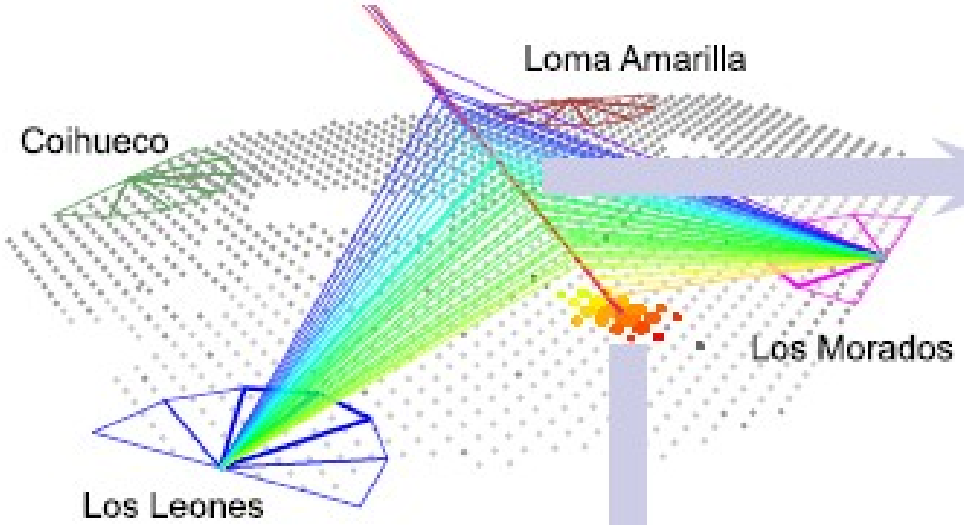
$\sigma_{X_{\max}} < 20\,\mathrm{g/cm^2}$
$\Delta_{\mathrm{sys}} \approx 15\,\mathrm{g/cm^2}$

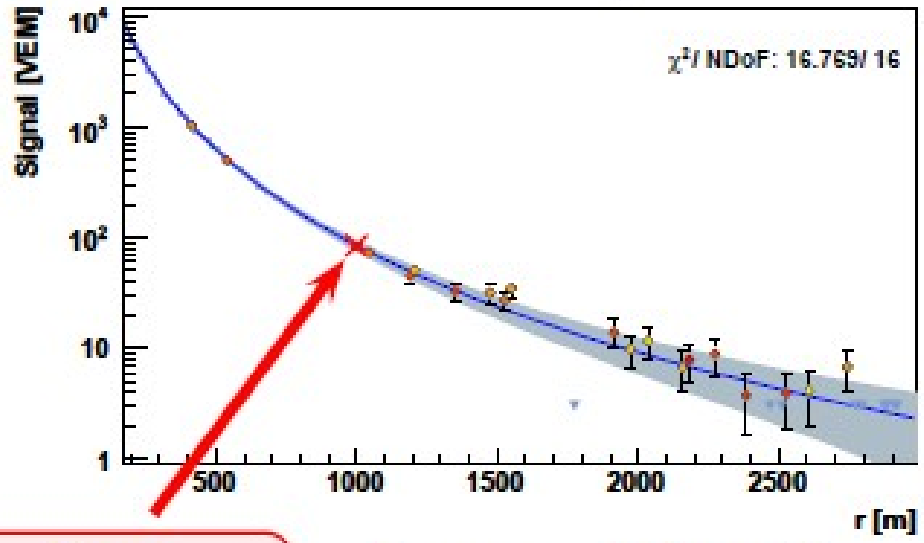
$X_{\max}$

$E_{\mathrm{cal}} = \int \mathrm{d}X \, \frac{\mathrm{d}E}{\mathrm{d}X}$

$\sigma_E / E \sim 8\,\%$
$\Delta_{\mathrm{sys}} \approx 22\,\%$

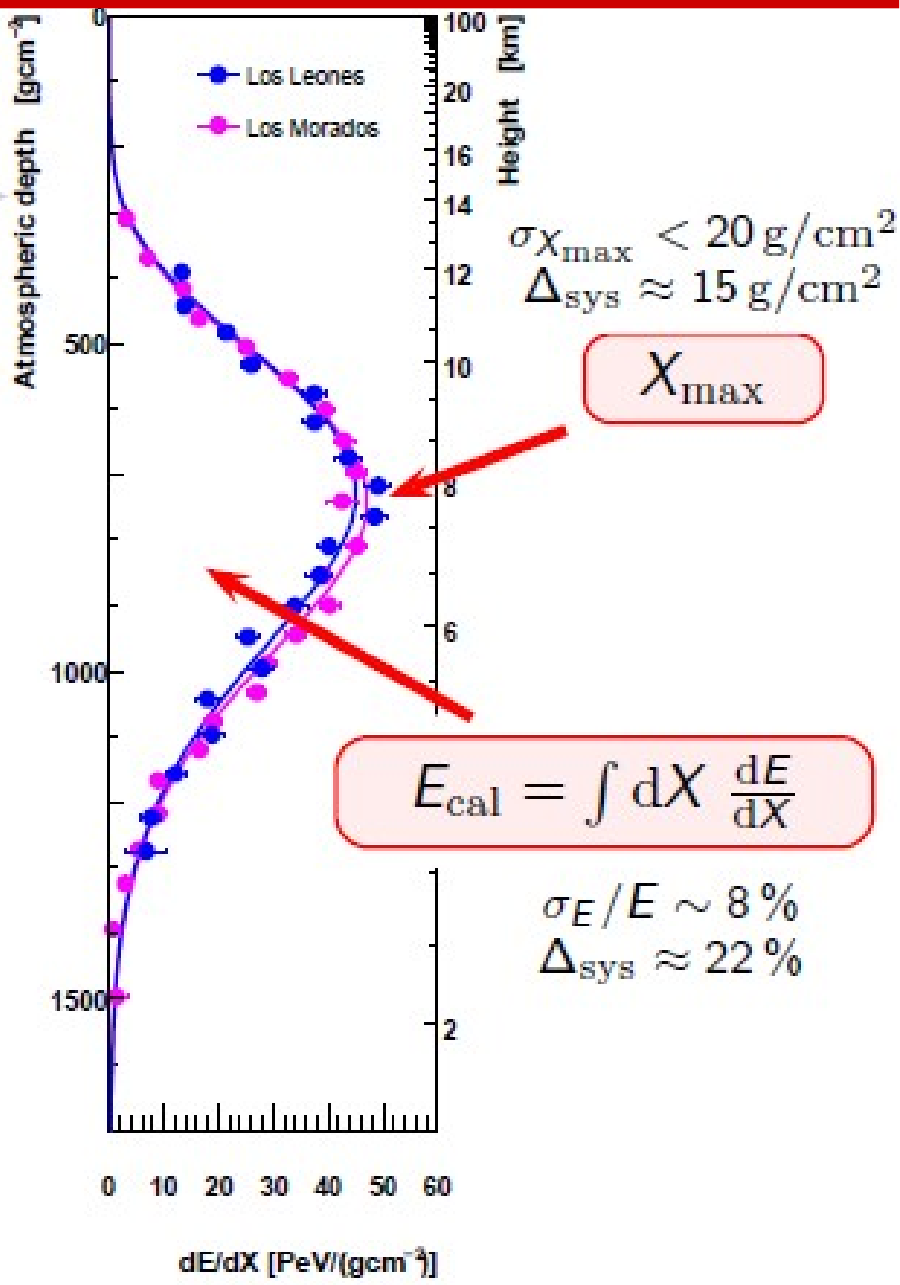
Observables at Auger





S_{1000}

$E_{\mathrm{surface}} = f(S_{1000}, \theta)$



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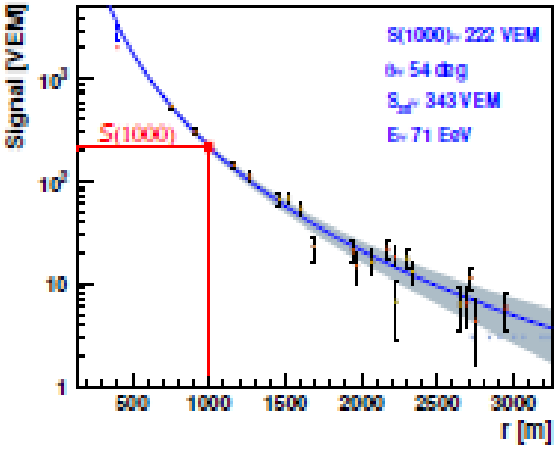
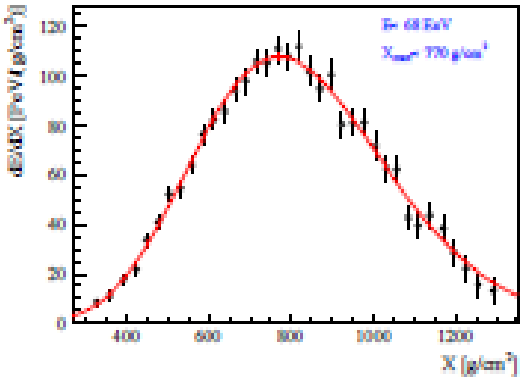
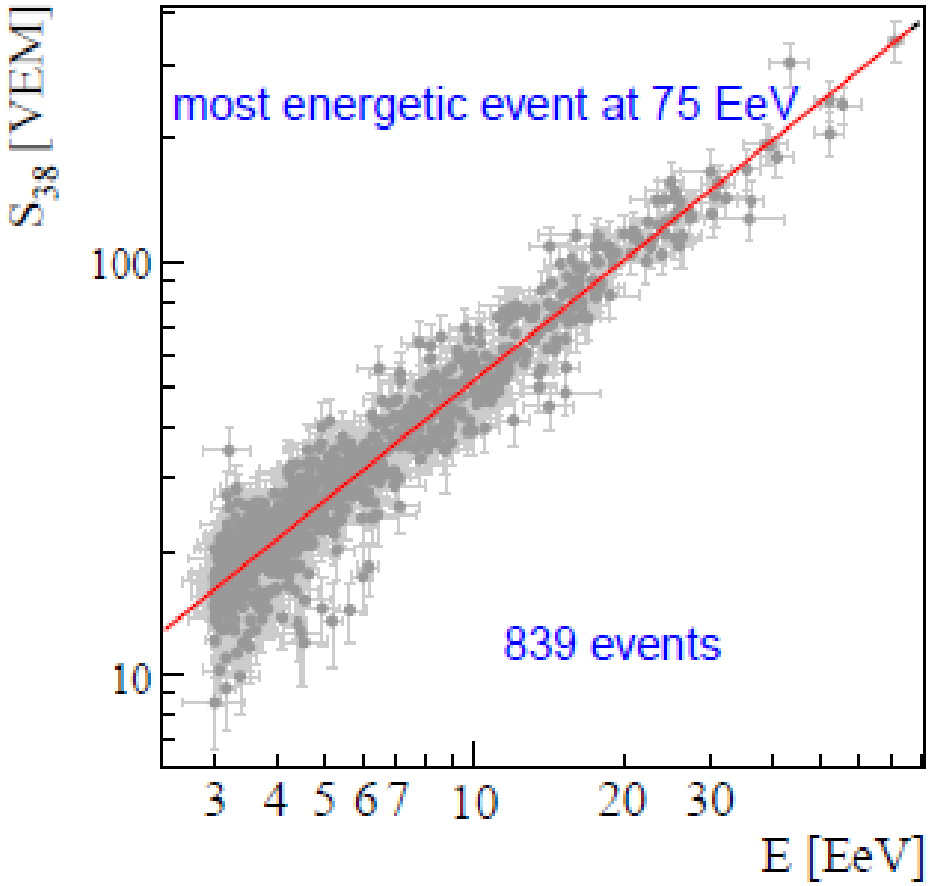
SD Energy Calibration

Calibration made using events with independent SD and Hybrid (FD + one SD station) trigger and reconstruction







Systematic uncertainty 7% (15%) at 10 EeV (100 EeV)

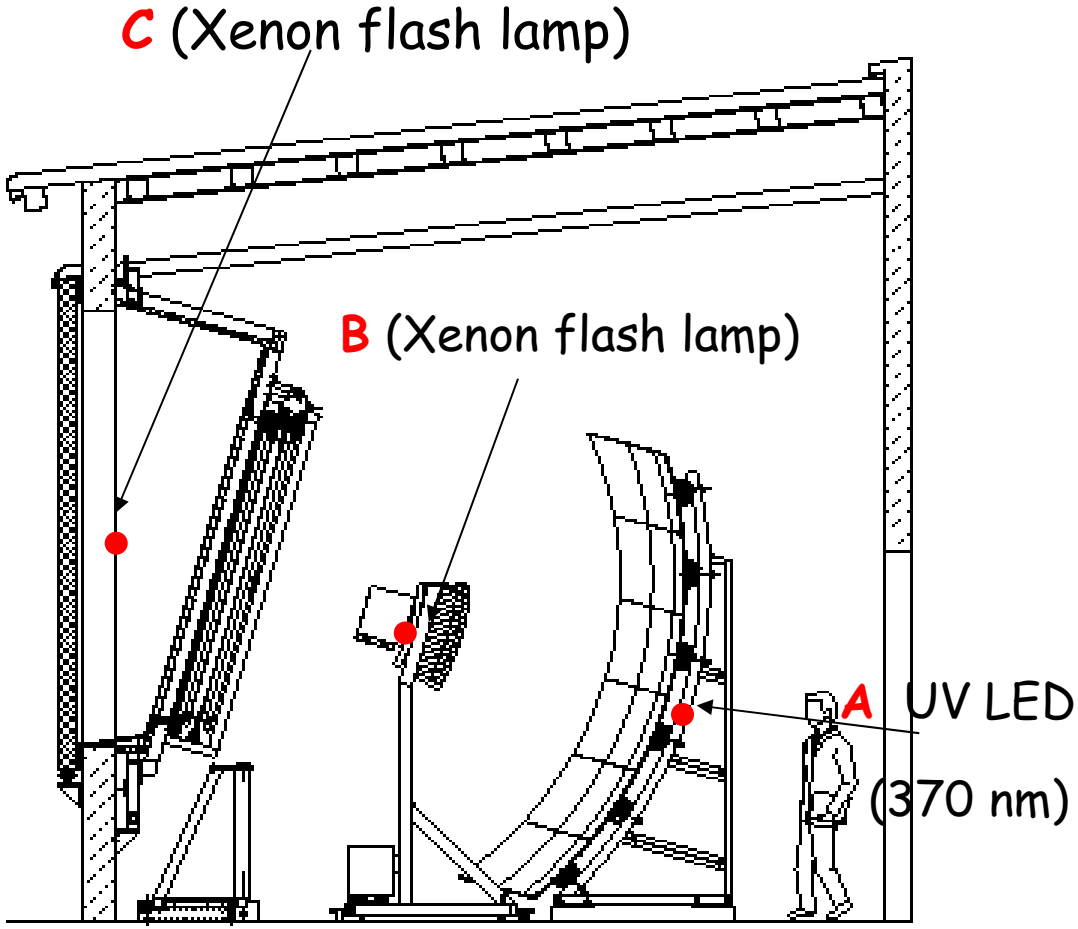
R. Pesce (1160) poster at this conference

FD Energy resolution & systematics

In Auger one single energy scale for both detection methods. Therefore FD resolution and systematics have impact on all measurements.

FD Energy Resolution:	**~7.6%**
light flux	4.5%
invisible energy	1%
geometry	2%
VAOD	5.5%
FD Energy Systematics:	**22%**
fluorescence yield	14% ← this Workshop
FD absolute calibration	9.5%
invisible energy	4%
reconstruction	10%
atmospheric effects	8%

FD calibration

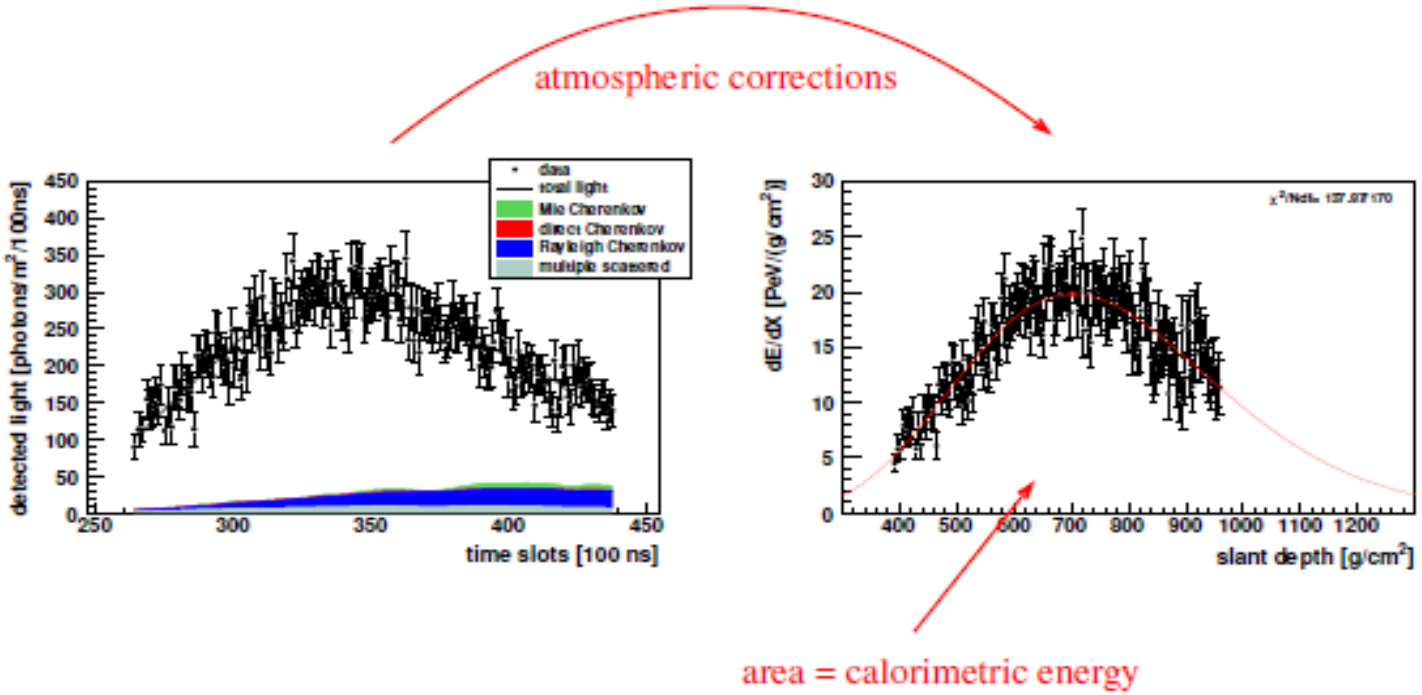


"Drum" absolute calibration done periodically
Relative calibration based on flashers and LED during data taking

$\sigma_{sys} \sim 9.5\%$

Hybrid Reconstruction

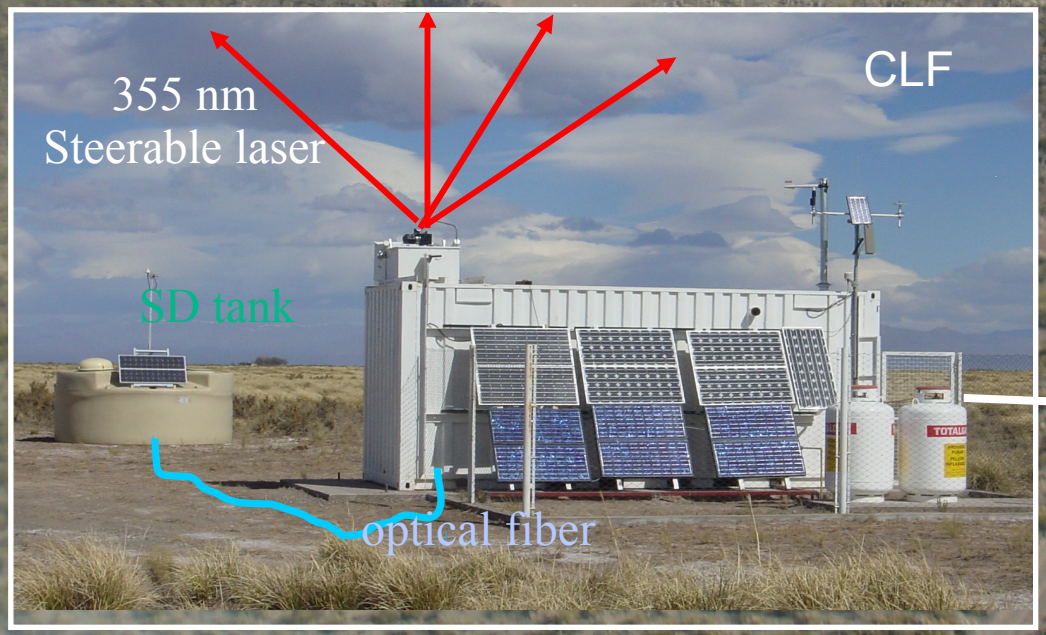
- Different photon contributions (fluorescence/Cherenkov, direct/scattered) obtained by matrix inversion of Fluorescence-Cherenkov equation
- Conversion to energy deposit through fluorescence yield model ('Nagano'+AirFly)

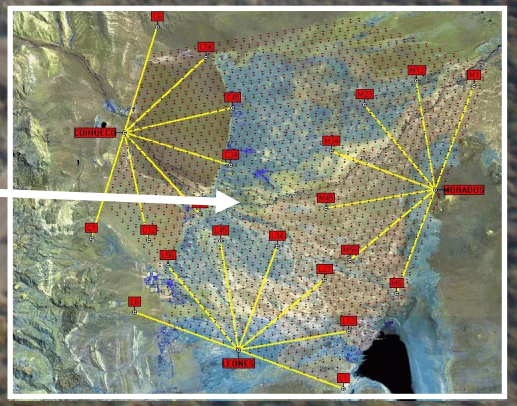


get total energy after correcting for invisible energy (μ, ν, about 10% at 10^{19} eV)

$\sigma_{sys} \sim 10\%$

Atmospheric Monitoring





An intense activity:

- Ground level state variables from five weather stations.
- Height-dependent profiles from meteorological radio-sondes launched from a helium balloon station (ended Dec. 2010 after 331 flights). Monthly models of atmospheric state variables derived.
- Meteorological model based on the Global Data Assimilation System (GDAS) developed by the National Oceanic and Atmospheric Administration.
- Aerosol monitoring from two central lasers (CLF / XLF) and four elastic scattering lidar stations
- two aerosol phase function monitors (APF) and two optical telescopes (HAM / FRAM).
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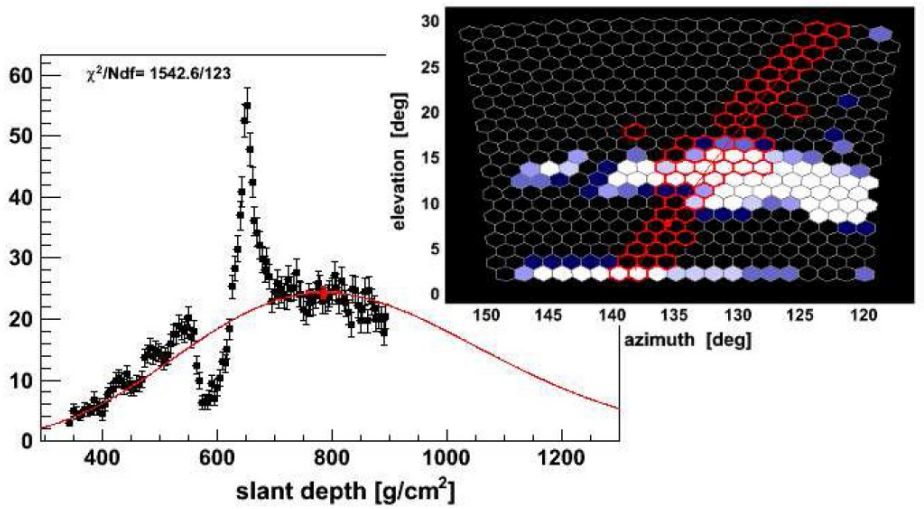

New in event reconstruction

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- Next year a Raman lidar (currently tested in Colorado) for the Super-Test-Beam project.

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scattering lidar stations
- two aerosol phase functi
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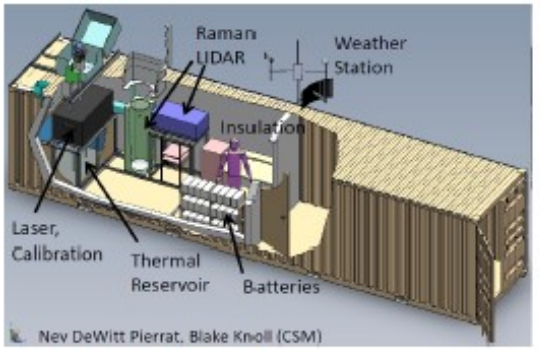
- Next year a Raman lidar
Test-Beam project.

Improved calibration techniques

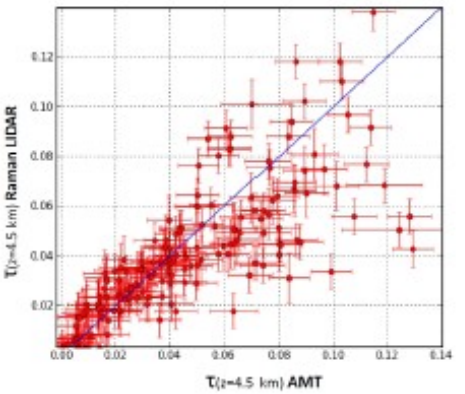


combination of

- stable solid state laser
- automatic laser calibration
- Raman LIDAR

to be installed at Auger in 2012

first tests in Colorado:



L. Wiencke [Auger Coll.], icrc741

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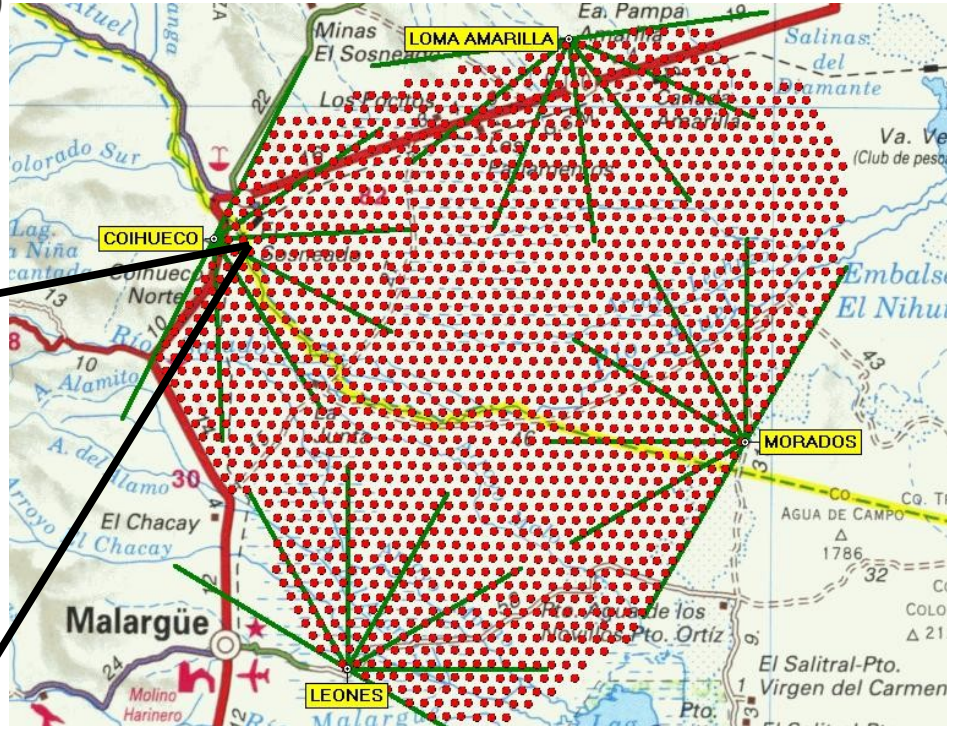
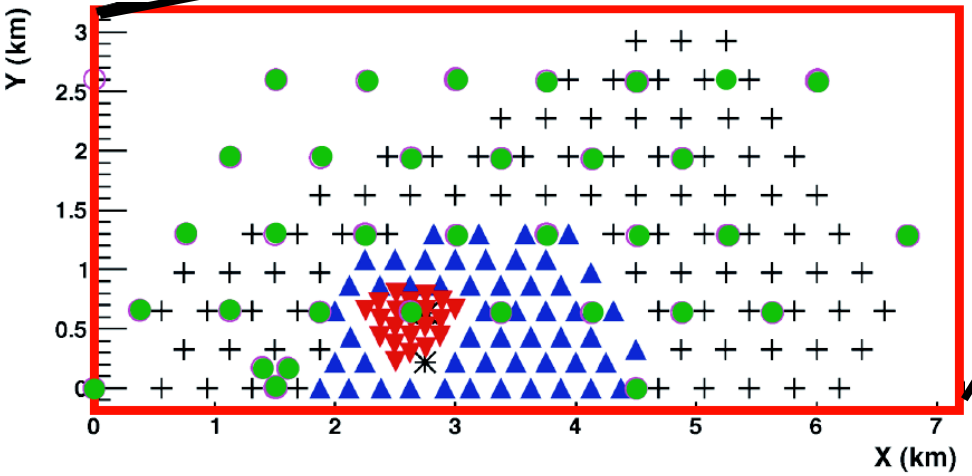
$\sigma_{sys} \sim 8\%$

Auger 2011

- Construction ended Apr. 2008
- Enhancements for Detection @ Low Energies:
  - **HEAT** *(High Elevation Auger Telescopes)*
  - **AMIGA** *(Auger Muon and Infill Array)*
  - + **AERA** array of radio detectors





infill array (750 m spacing)

▼▲ + AERA radio antennas

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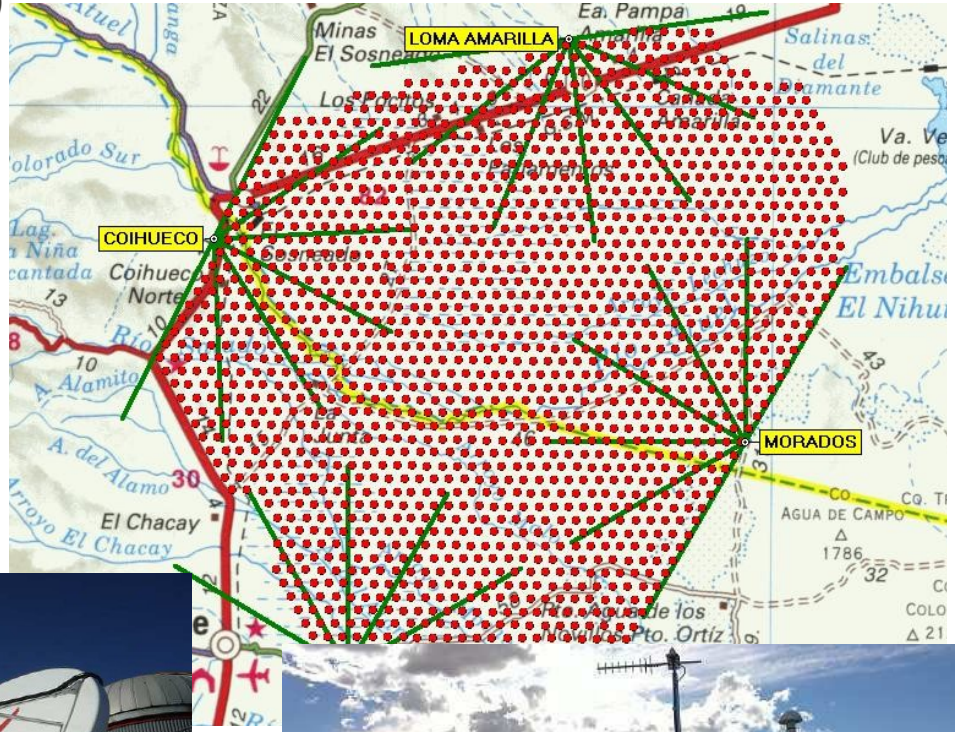
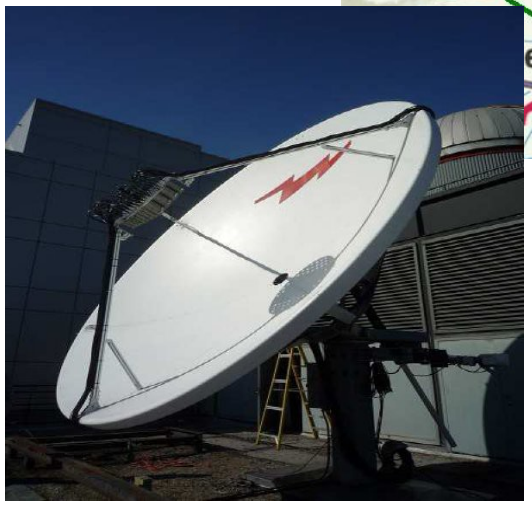
  - **HEAT** *(High Elevation Auger Telescopes)*
  - **AMIGA** *(Auger Muon and Infill Array)*
  - \+ **AERA** array of radio detectors
- **New R&D: MW fluorescence detection**

[after Gorham et al., PR D 78 (2008) 032007]

Towards an FD with 100% duty cycle?



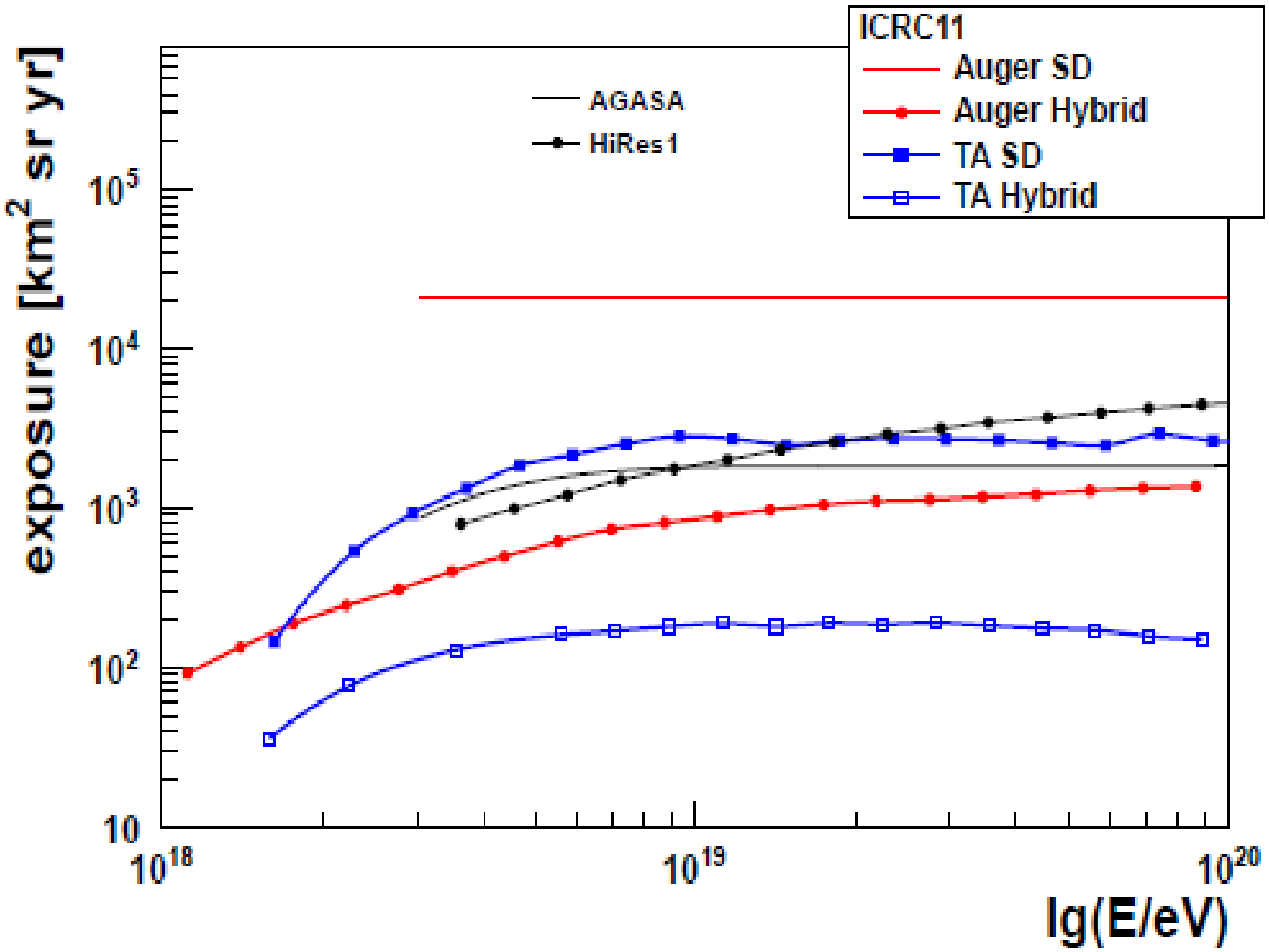
AMBER



MIDAS

EASIER

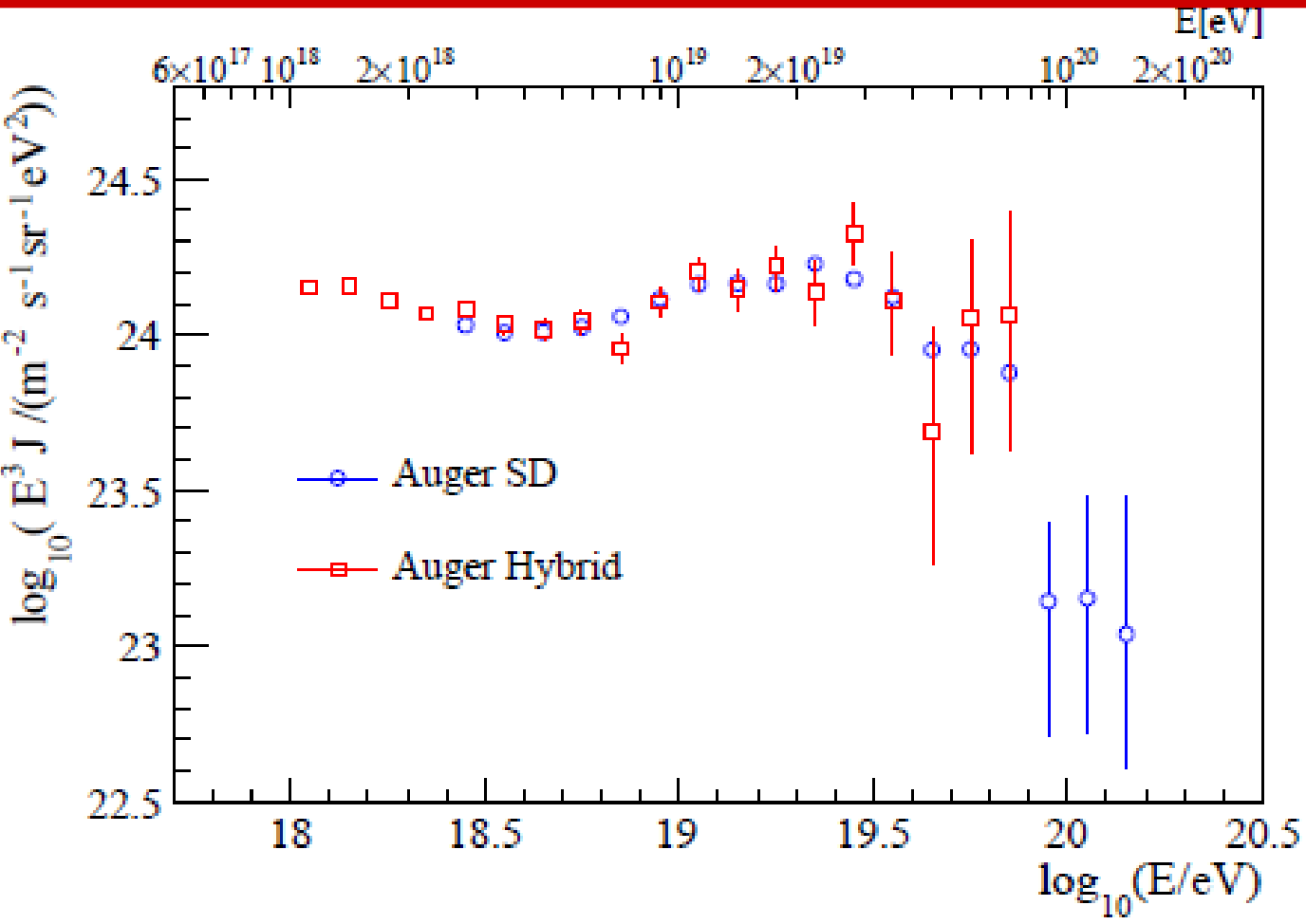
Exposures 2011



A few selected physics results

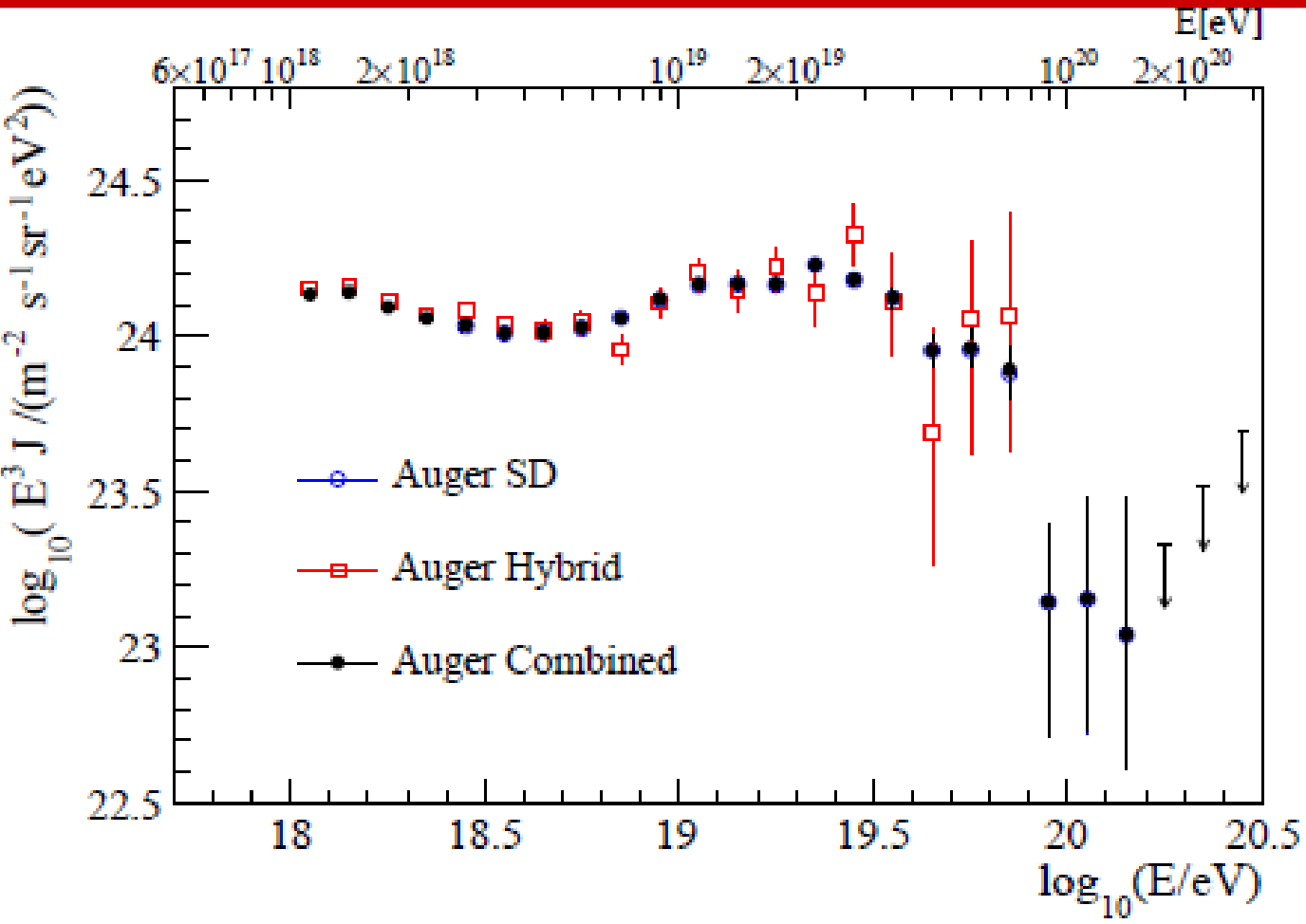
- **Energy Spectrum**
- **Chemical Composition**
- **Arrival directions**

Vertical Spectrum



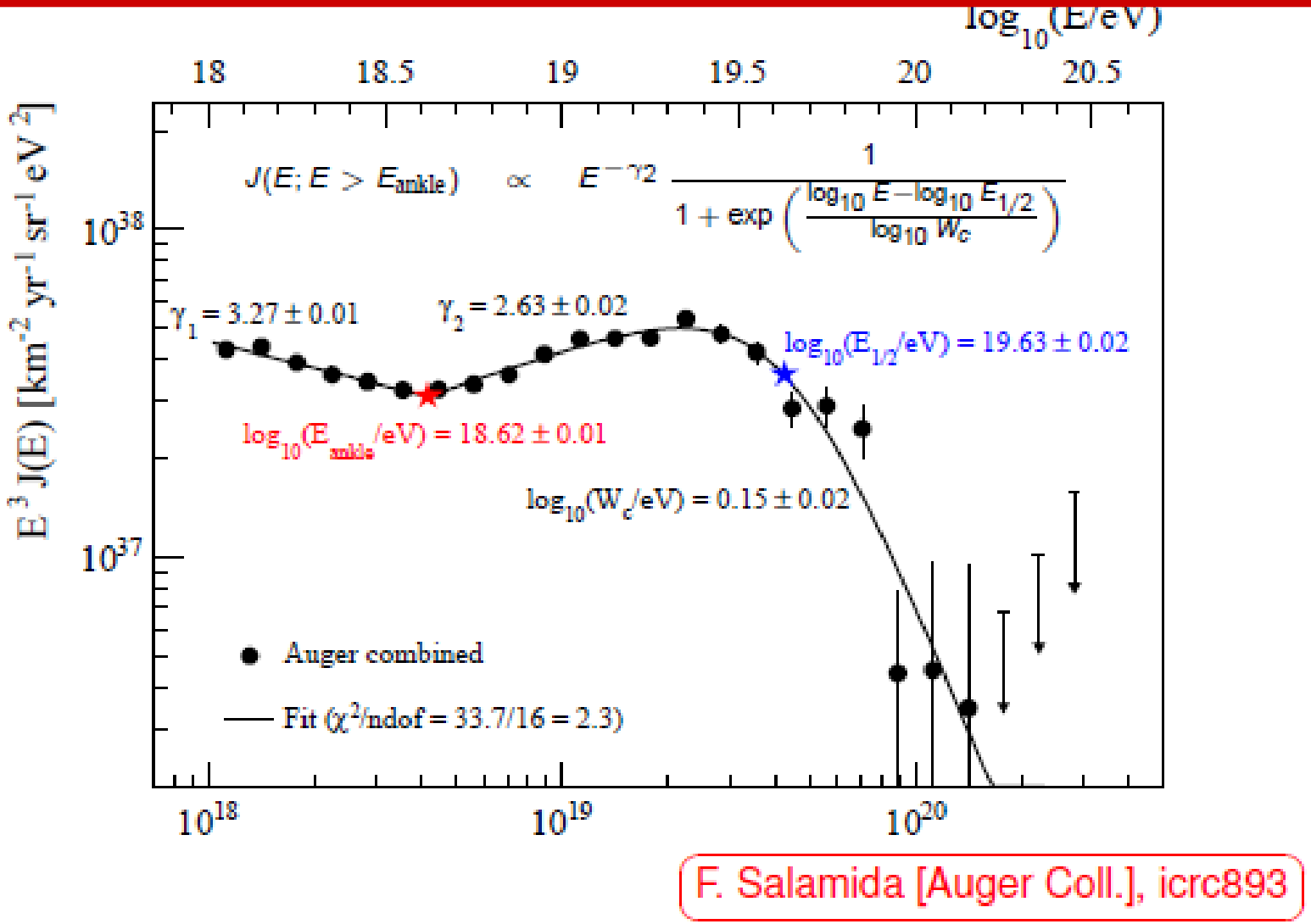
F. Salamida [Auger Coll.], icrc893

Vertical Spectrum



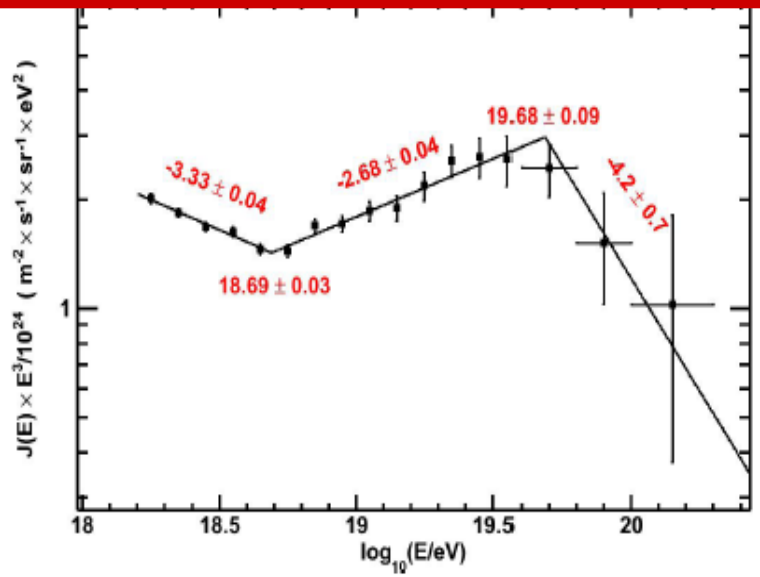
F. Salamida [Auger Coll.], icrc893

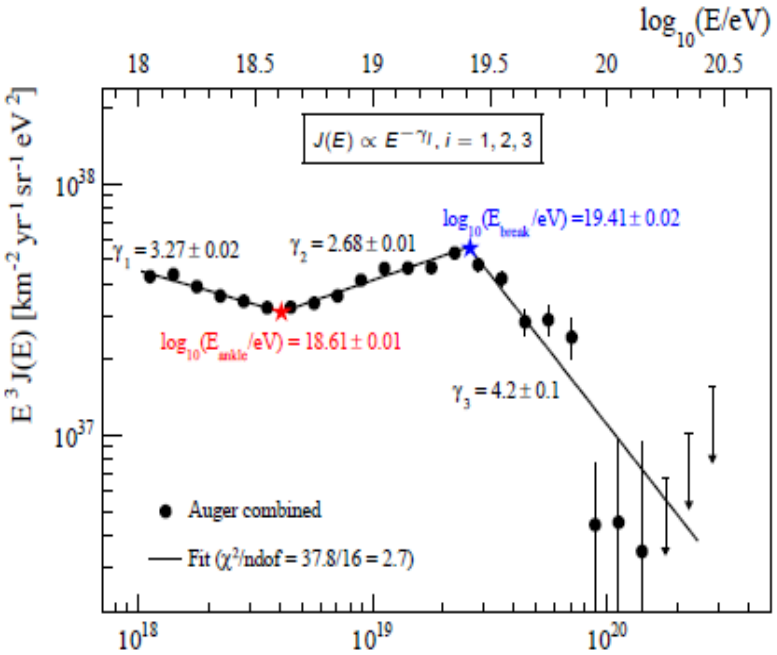
Spectral Features



F. Salamida [Auger Coll.], icrc893

Comparison of Spectral Features





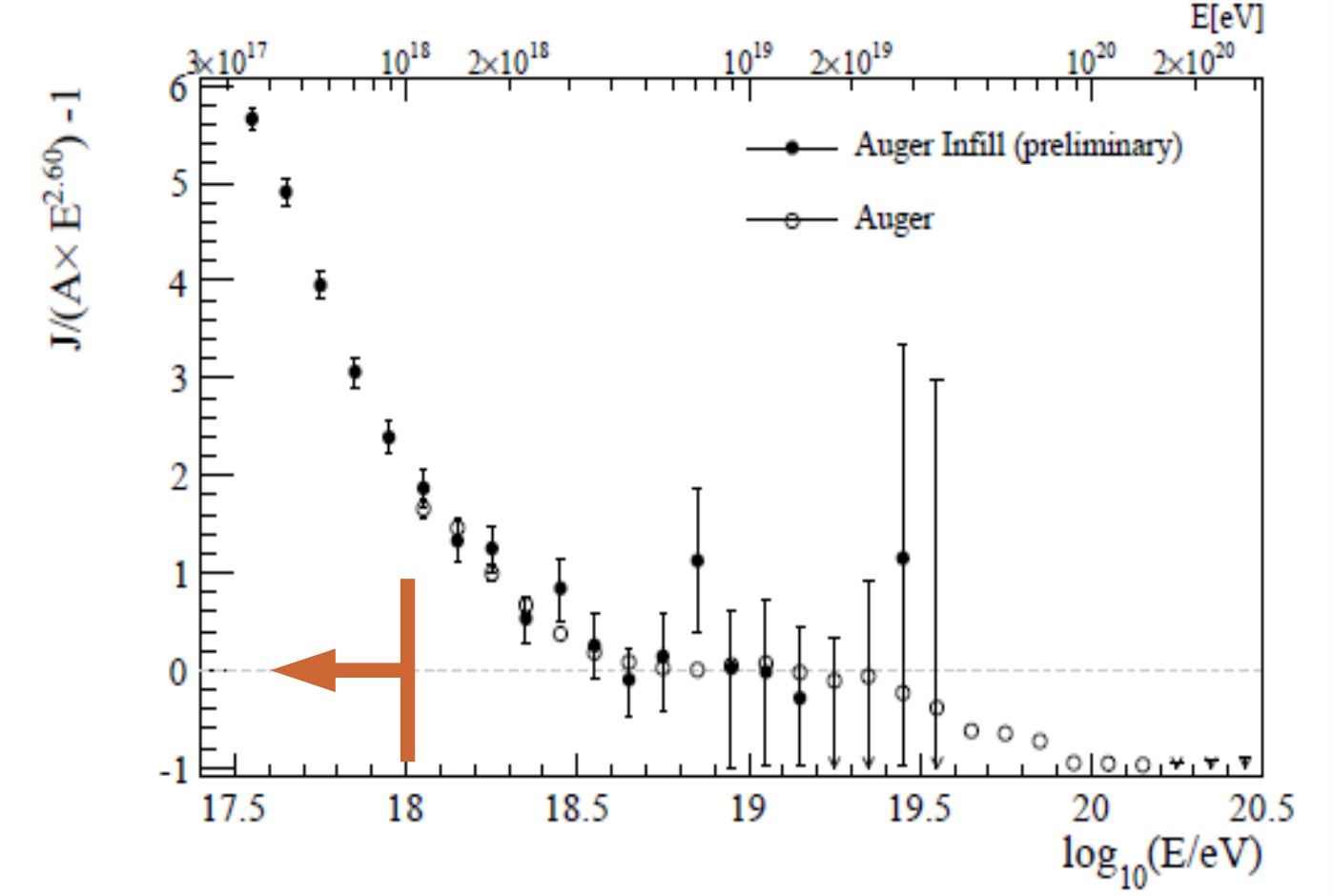
	TA	Auger
γ_1	3.33 ± 0.04	3.27 ± 0.02
γ_2	2.68 ± 0.04	2.68 ± 0.01
γ_3	4.2 ± 0.7	4.2 ± 0.1
$\lg(E_1/\mathrm{eV})$	18.69 ± 0.03	18.61 ± 0.01
$\lg(E_2/\mathrm{eV})$	19.68 ± 0.09	19.41 ± 0.02

B. Stokes [TA Coll.], icrc1297

F. Salamida [Auger Coll.], icrc893

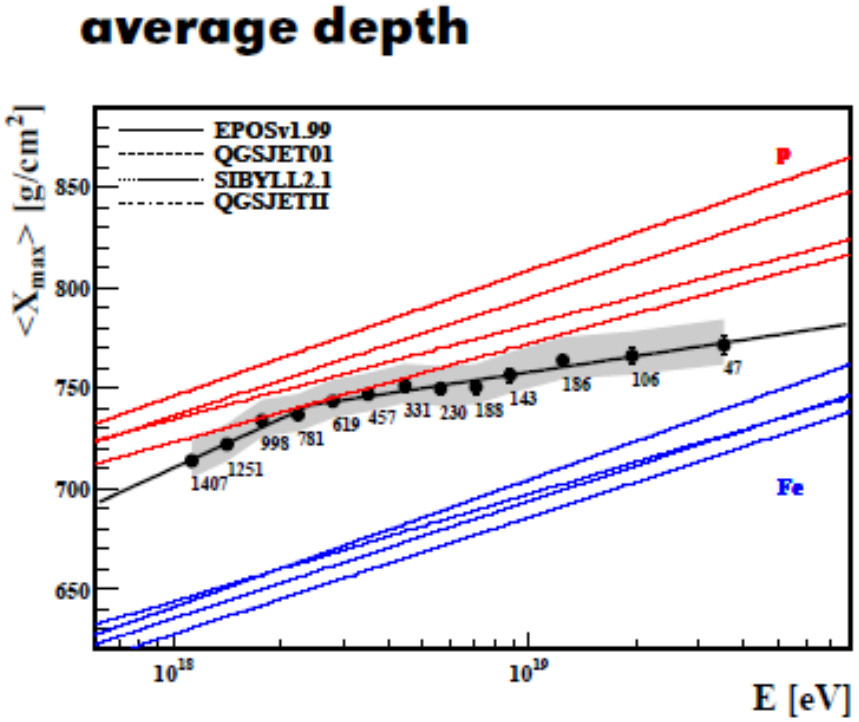
From ICRC 2011 rapporteur talk

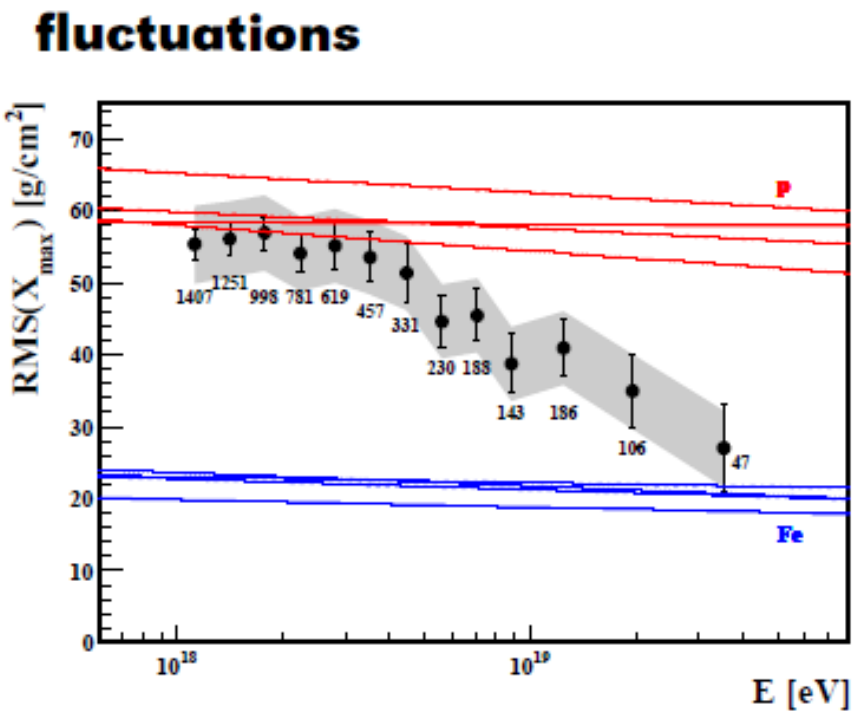
Preliminary Infill Spectrum



- extends the energy range down to 3×10^{17} eV (No resolution correction!)
- very good agreement with the combined spectrum (F.Salamida, talk 0893)
- slope for $E < 3 \times 10^{18}$ eV: $-3.33 \pm 0.03(\text{stat}) \pm 0.1(\text{sys})$

Chemical Composition





Unbiased selection:

- Select the distance to the SD station, and zenith angle so that the tank trigger probability does not depend on the mass of primary

- Select event geometries that allow to sample the whole Xmax distribution (from measurement).

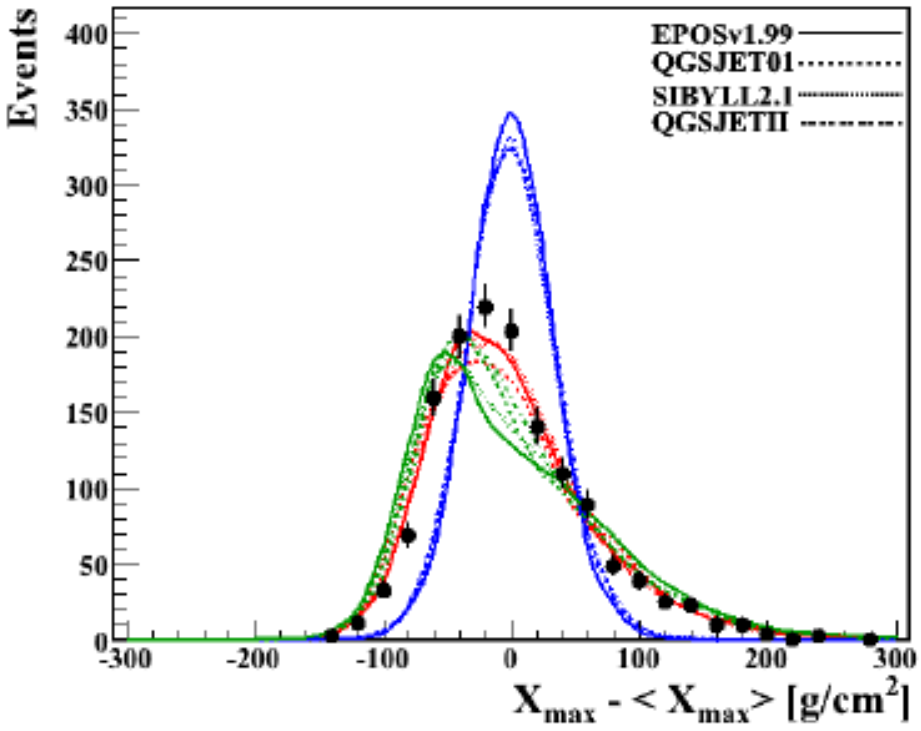
P. Facal [Auger Coll.], icrc725

Xmax resolution from MC ~ 20 g/cm^2

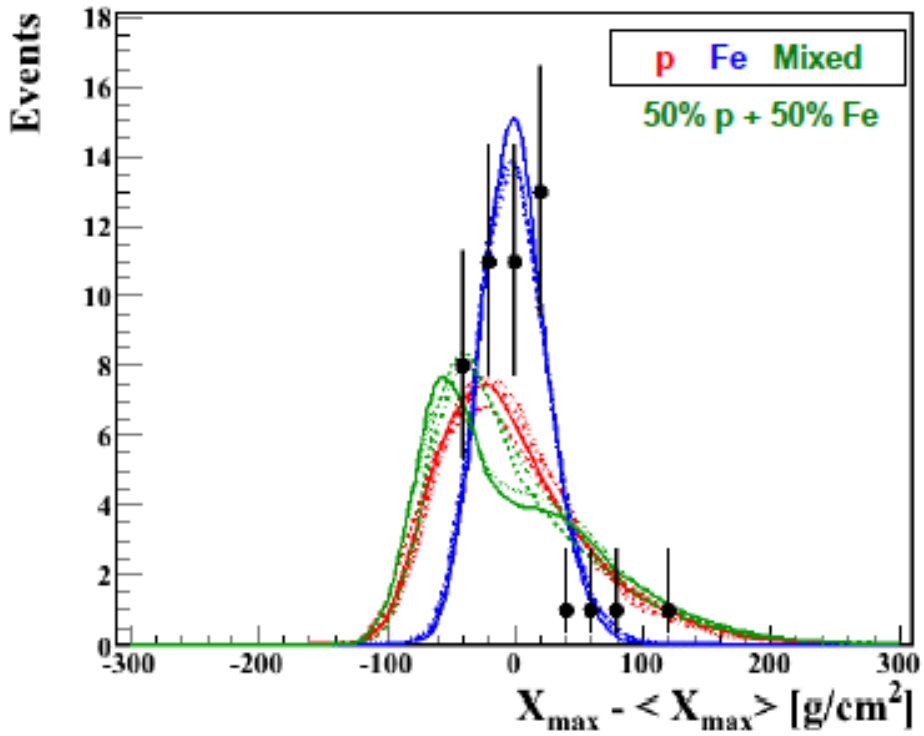
Chemical Composition

Subtract $\langle X_{max} \rangle$ to each of the distributions and compare only the shapes

18.1 > log(E/eV) > 18.0

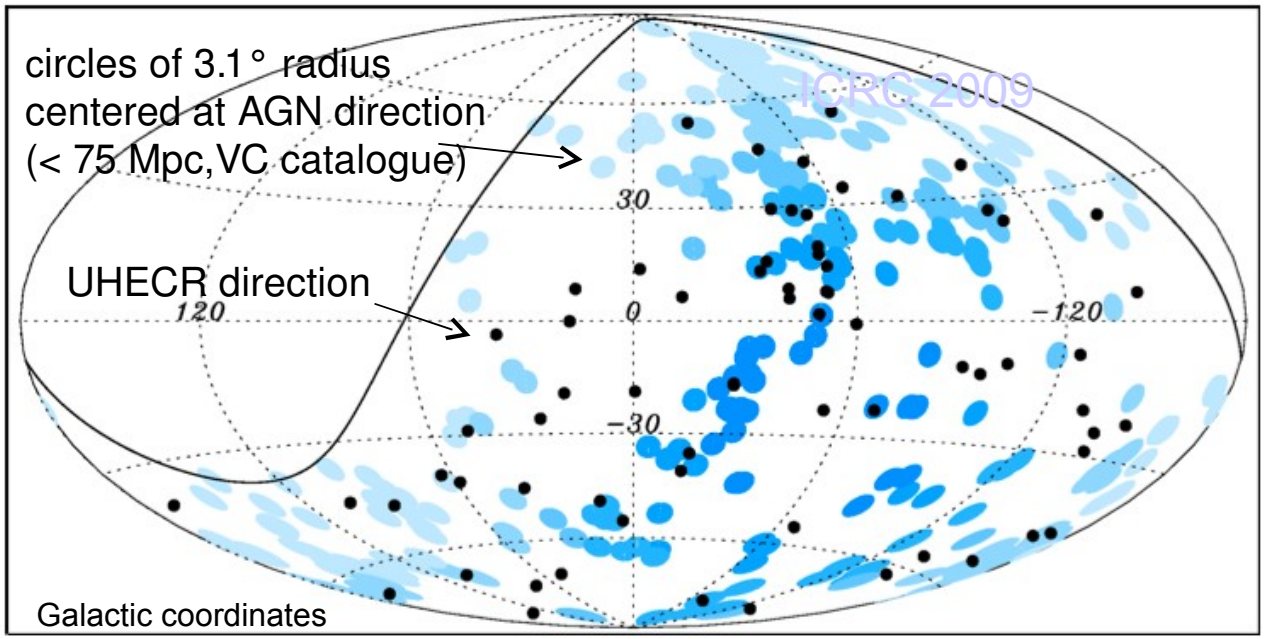


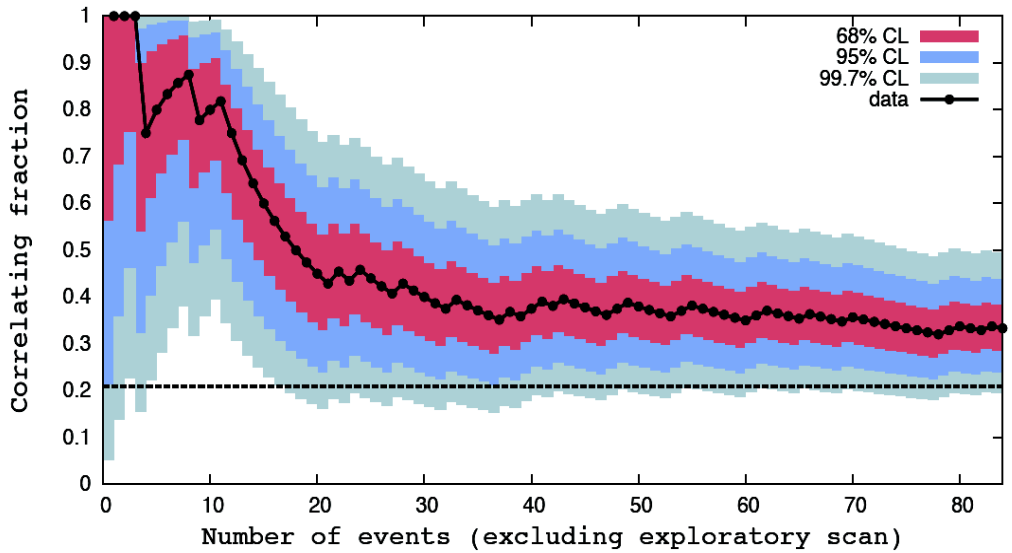
log(E/eV) > 19.4



Fits light to heavier

Arrival Directions





69 events E> $5.5 \cdot 10^{19}$ eV

Astropart. Phys. 34 (2010) 314

Update including June 2011

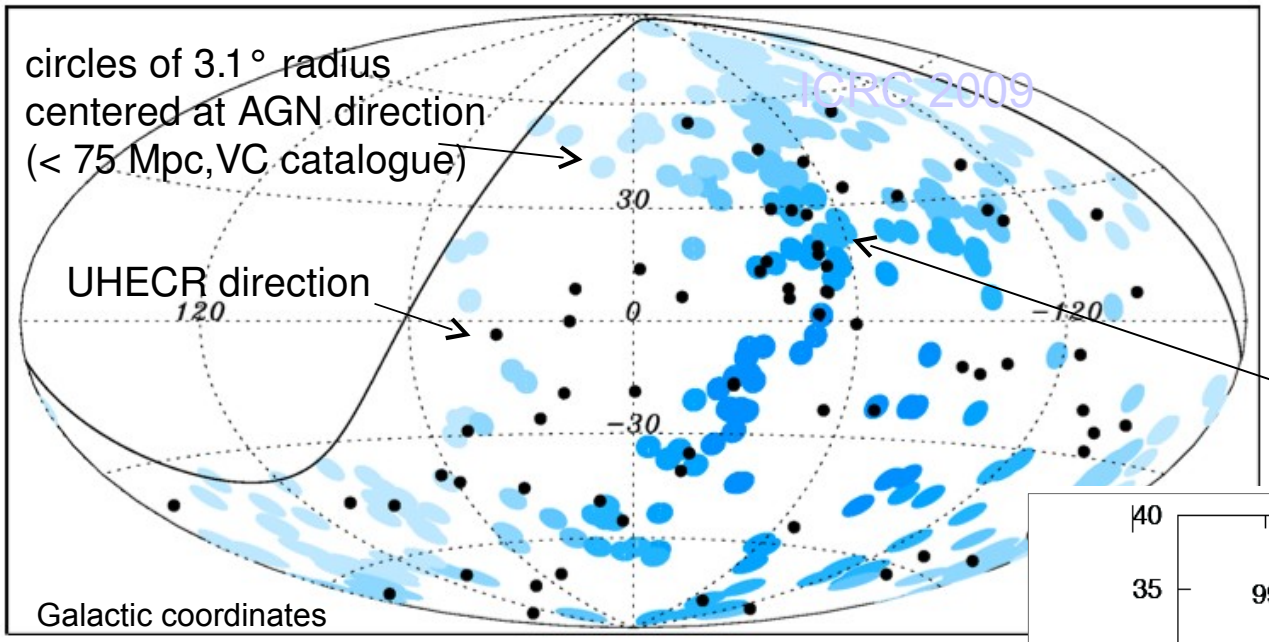
33±5%

Total: 28/84

P=0.006

Telescope Array:
8/20 = 40%
with iso-bkg = 24%

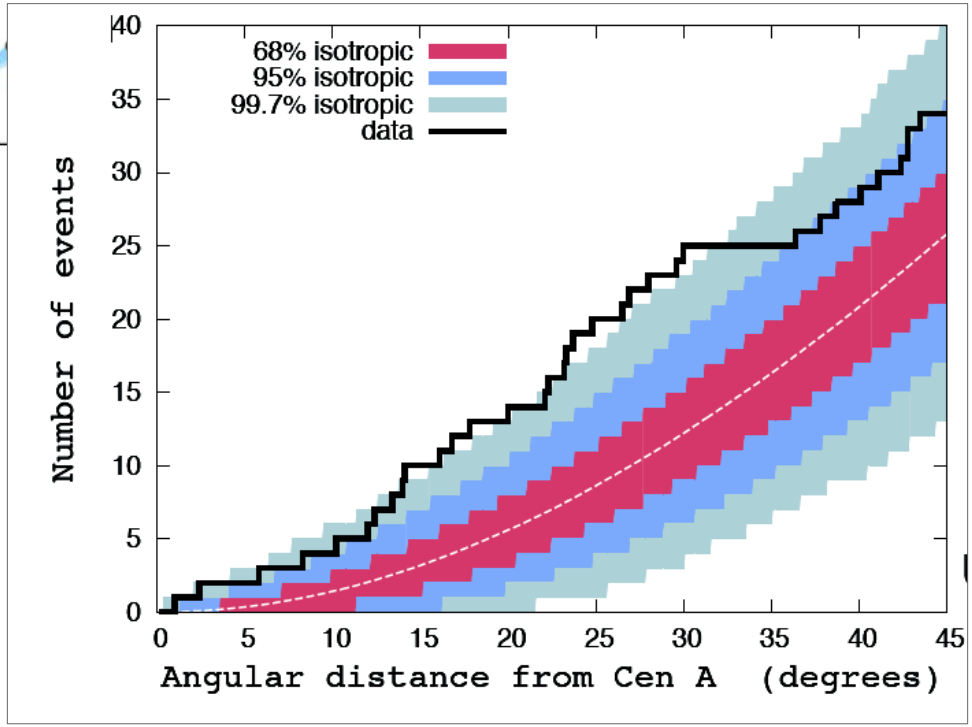
Arrival Directions



69 events E> 5.5·10[19] eV

Astropart. Phys. 34 (2010) 314

Cen A radiogalaxy
3.8 Mpc



KS test yields 4% isotropic probability

Largest departure now at 24°:

19 observed / 7.6 expected

...and more on:

- first p-Air and pp cross-section at $\sqrt{s}$=57 TeV
- μ-deficit by up to factor of ~2 in all interaction models

- SD related Xmax observations
- Update on photon and neutrino limits (up- and down-going)

- first harmonic analyses
- first point source searches
- B-field and source density estimates

Please refer to
ICRC 2011 Auger Highlight Talk (K-H. Kampert)

http://arxiv.org/abs/1107.4809
http://arxiv.org/abs/1107.4807
http://arxiv.org/abs/1107.4806
http://arxiv.org/abs/1107.4805
http://arxiv.org/abs/1107.4804

Summary and outlook

Auger Observatory taking data with larger and larger statistics.
Wide Science program
New detectors and new methods going to be exploited.

Auger looking forward with interest to new TA results.
Preliminary comparisons:

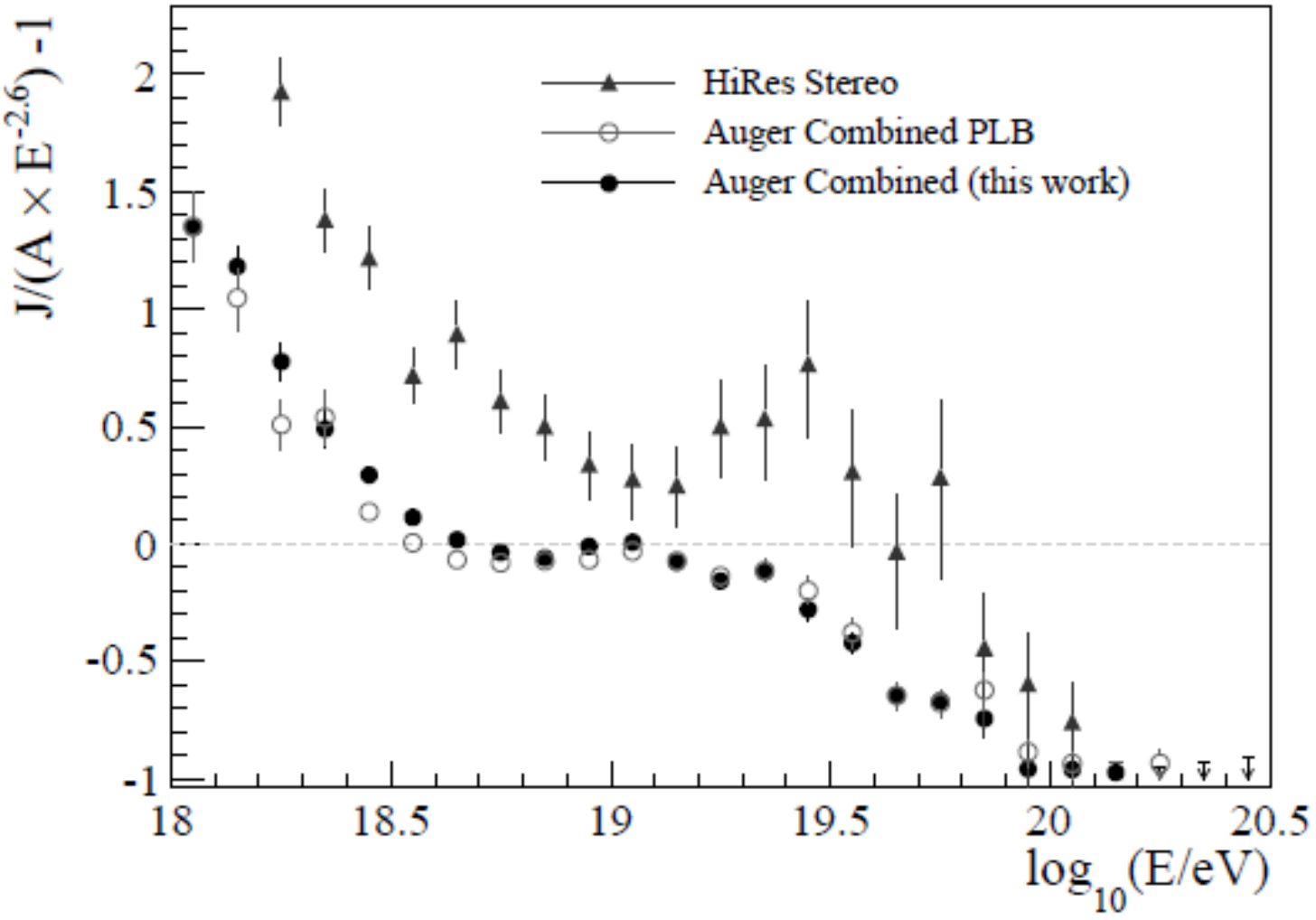
- good agreement on spectrum features (apart E scale)
- compatible anisotropy in arrival directions of the most energetic CR's
- different composition results but also measurement strategies

We expect that this Workshop will help a better understanding in UHECR through common energy scale and reconstruction methods

Thanks!

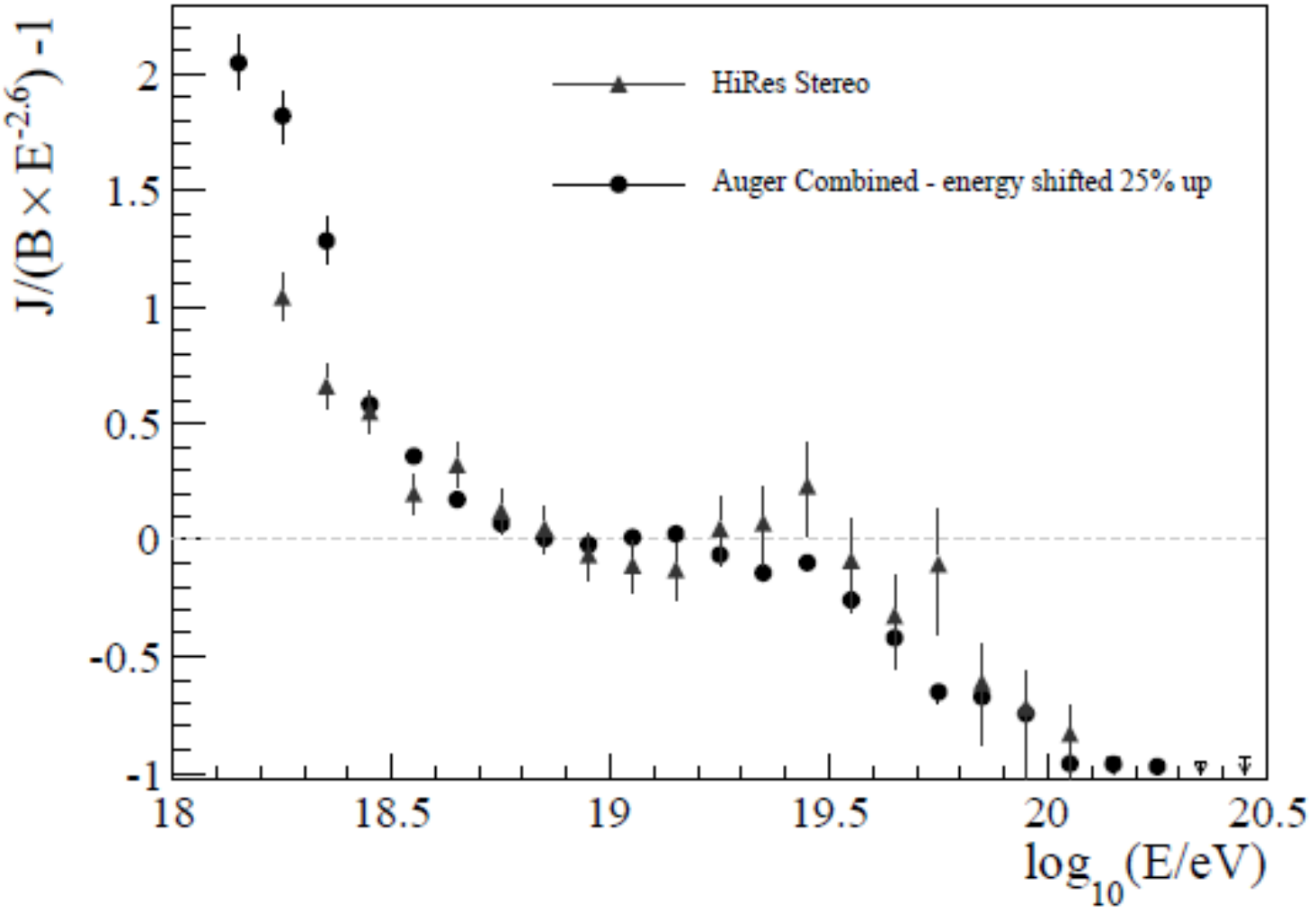
backup

Residuals



- difference w.r.t PLB due to changes in calibration curve
- very high statistics, spectral features very well defined

Backup -Residuals



- Energy shift of 25% applied to Auger combined spectrum