Les Rencontres de Physique de la Vallée d'Aoste

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Cosmic Rays Spectrum and Composition with the Auger Experiment

Claudio Di Giulio* for the Pierre Auger Collaboration

PIERRE AUGER OBSERVATORY

*INFN Roma Tor Vergata

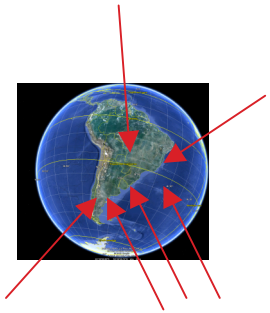
Outline

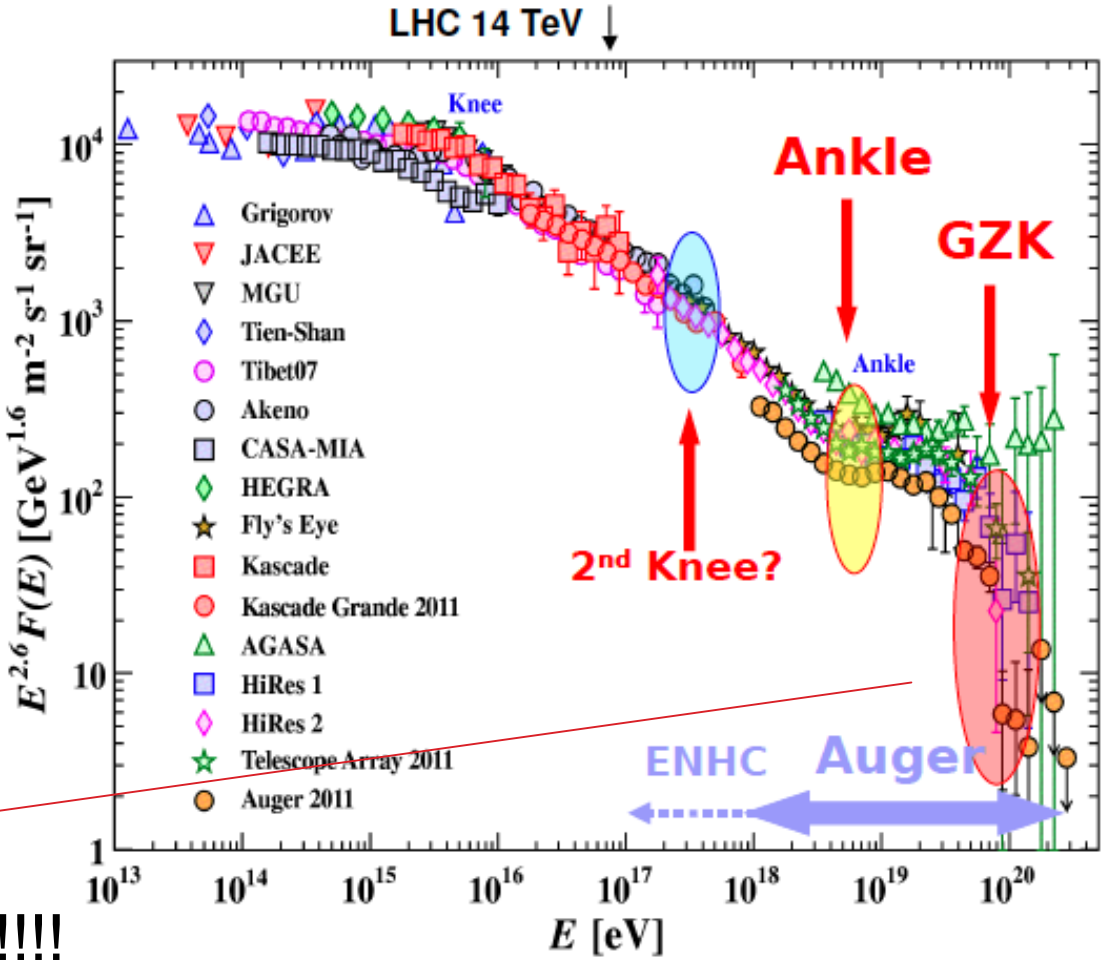
- Physics goals
- Detector description
- Performance and observables
- Results

The physical goals:

The nature of the ultra-high energy cosmic rays (UHECRs):

- Energy Spectrum
- Composition
- Arrival directions



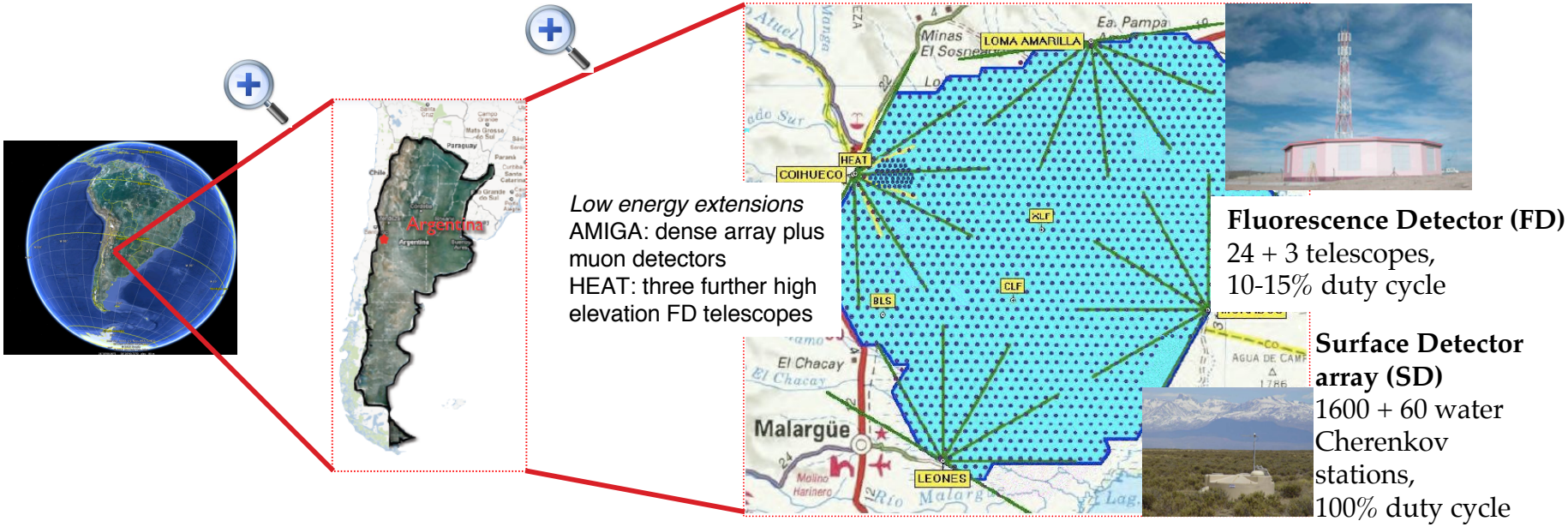


Particle Data Group

1 particle/km^2 for year!!!!

We need big detector….

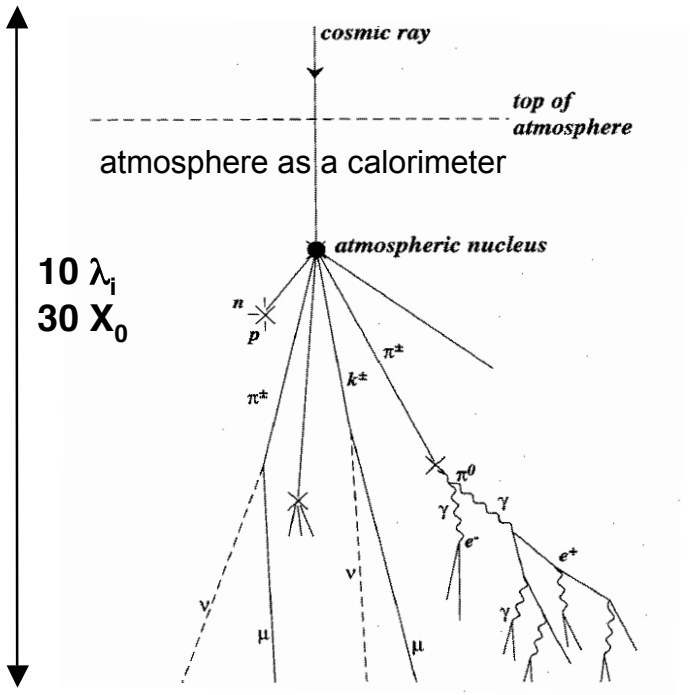
The Pierre Auger Experiment



Malargüe (Mendoza, Argentina) 1400 m s.l.

Consist of a surface array of 1600 water Cherenkov detectors on about 3000 km^2 on a triangular grid of 1.5 km spacing, overlooked by 27 air fluorescence telescopes grouped in 4 sites.

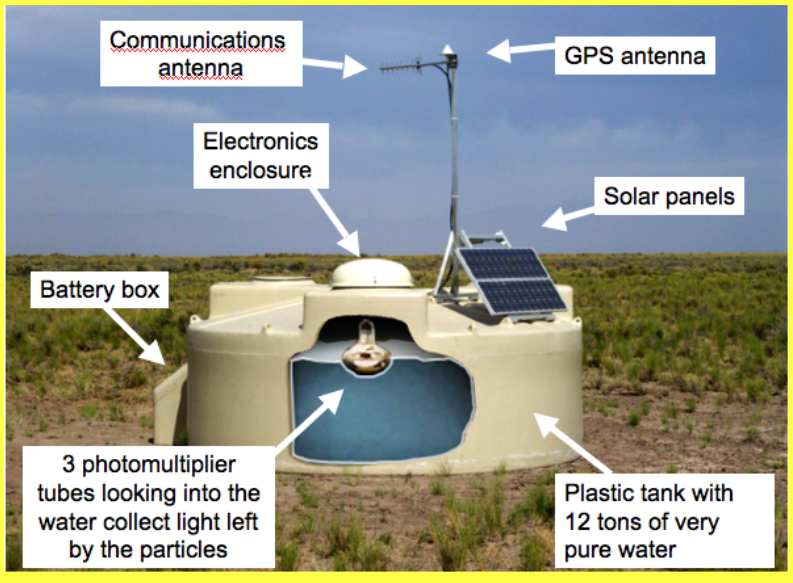
The Pierre Auger Experiment: SD



at ground millions of particles

… detectors in coincidence

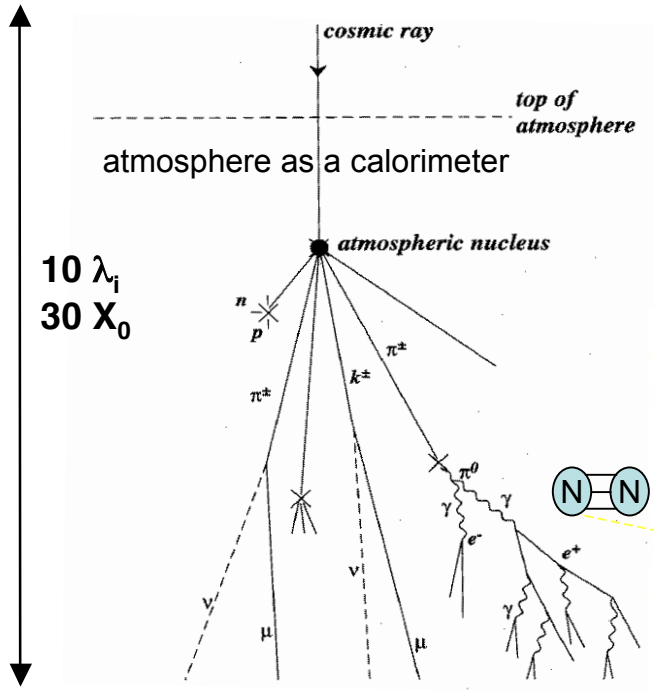
Samples the density of secondaries at the ground

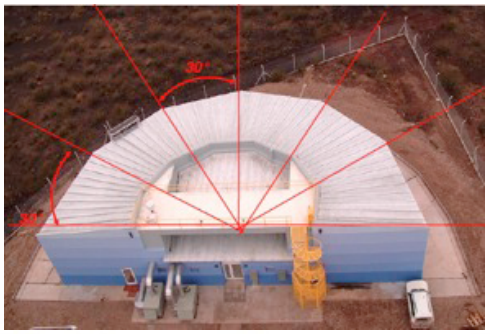


Surface Detector

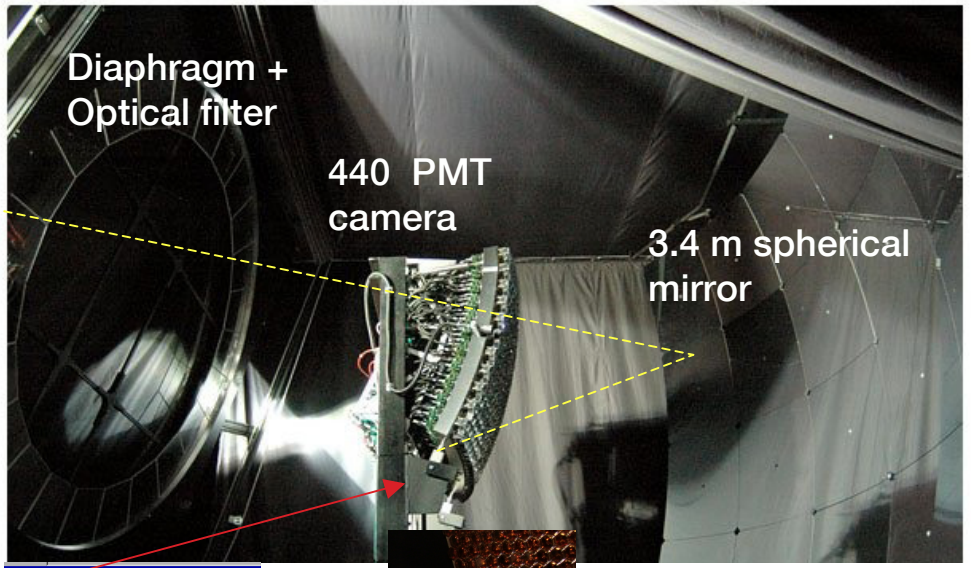
- Shower size ≈ E
- Time ≈ direction
- 100% duty cycle

The Pierre Auger Experiment: FD



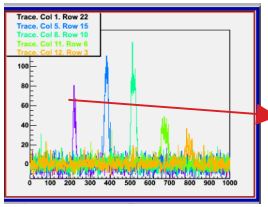


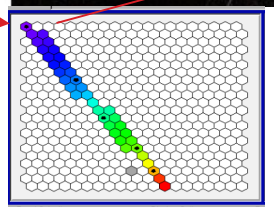
The fluorescence telescope detect the UV light between 300-400 nm due to the de-excitation of atmospheric nitrogen. (fluorescence light).



Fluorescence Detector

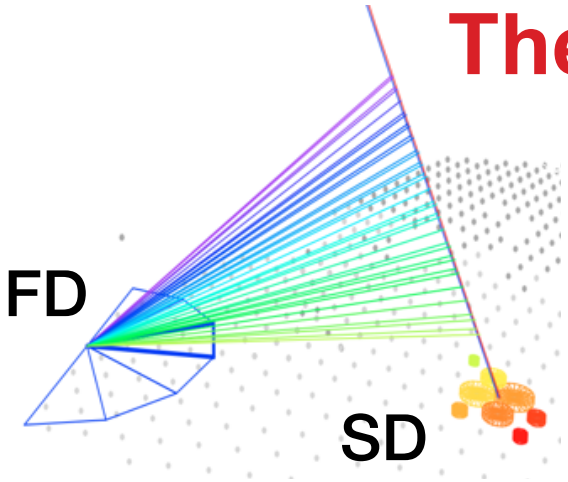
- E + longitudinal development
- Time ≈ direction
- ≈ 10% duty cycle

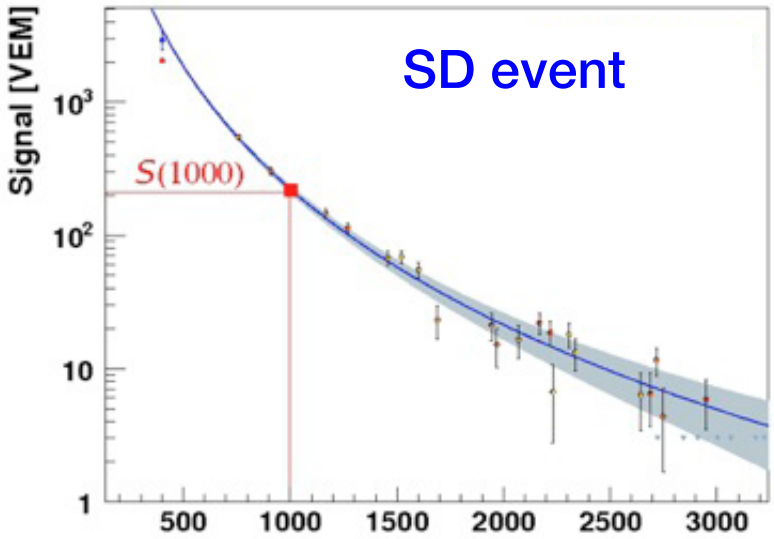




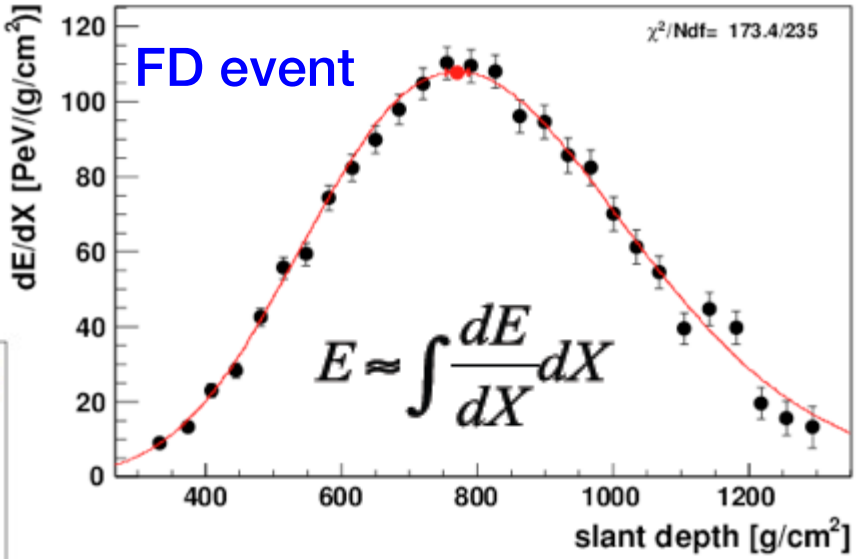
Last L.A.
PMT in 2006

The Hybrid detector:





• Tank signal proportional to shower density.
• The primary energy is proportional to the signal S(1000) at 1000 m from the showe core



- observation of longitudinal profile
- calorimetric energy (resolution~10%)

SD and FD combined in the **hybrid mode** (i.e. FD + at least 1 SD)

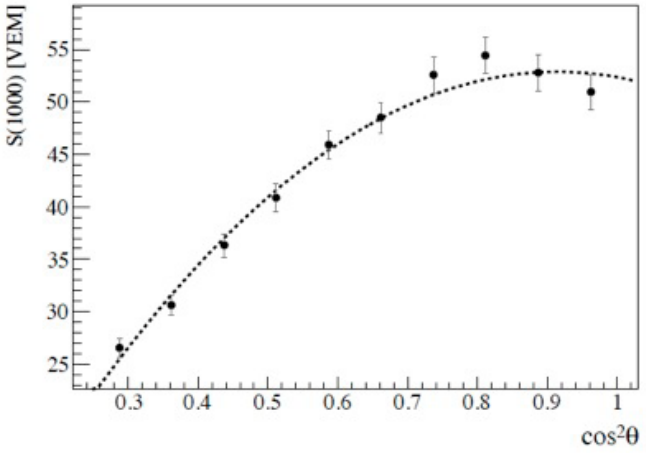
• accurate direction measurements

• calibration of the energy scale for SD events using golden hybrid data (FD + ≥ 3 SD stations).

The surface detector hybrid calibration

The "golden" hybrid events are used to calibrate all the detected the SD events. (almost independent of the hadronic interaction models)

convert to S38: S1000 that a shower would have produced if it has arrived with a zenith angle of 38°

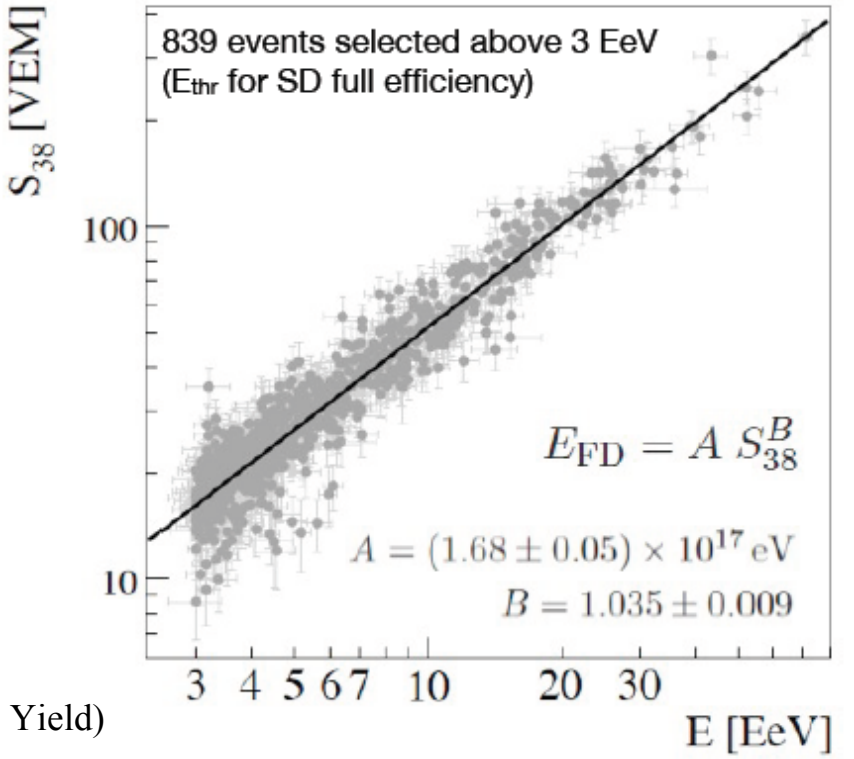


SD energy resolution: E_{SD}/E_{FD} ~ 15%

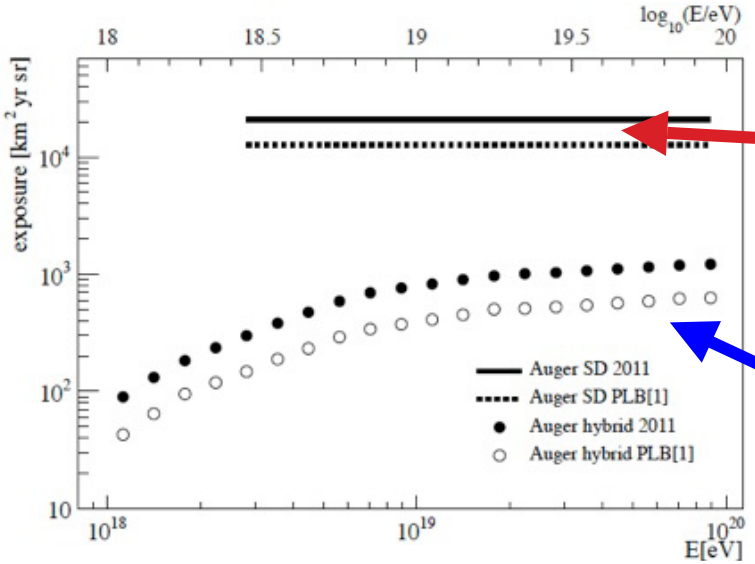
Systematic uncertainties:

- SD calibration: 7% at 10 EeV; 15% at 100 EeV
- FD energy scale: 22% (dominated by Fluorescence Yield)

R. Pesce for the Pierre Auger Collaboration, ICRC 2011, arXiv:1107.4809



The UHECR Spectrum:



SD Exposure (01/2004-12/2010)

-geometrical calculation

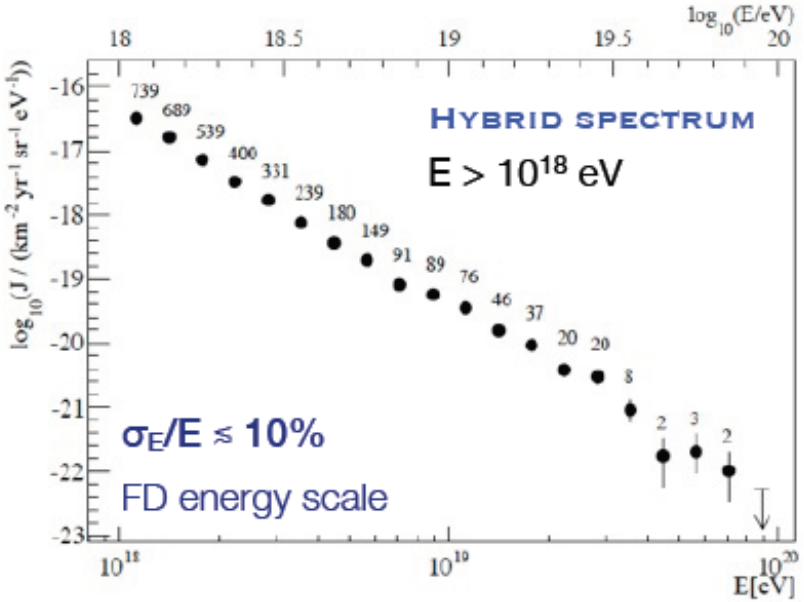
(~ 21000 km^2 yr sr)

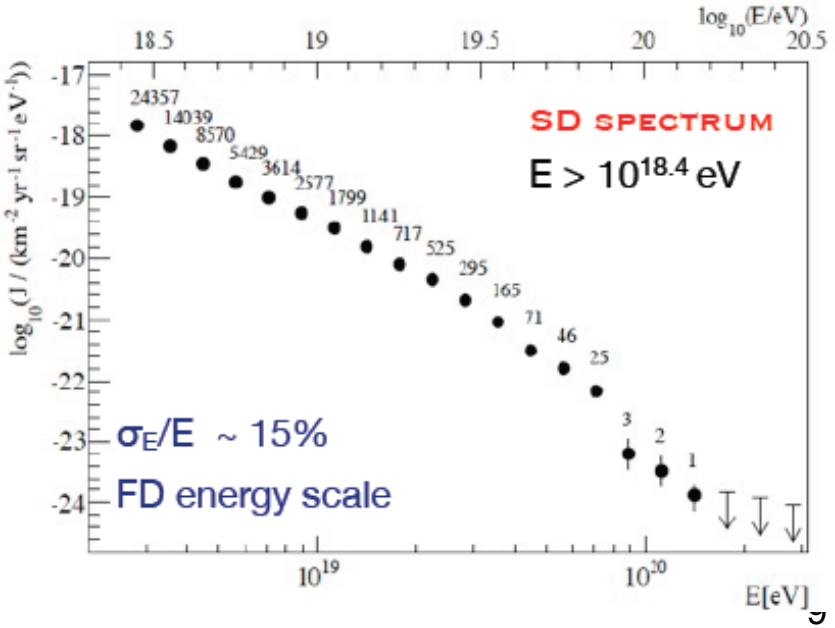
syst. uncertainties: ~ 3%

Hybrid Exposure (11/2005-09/2010)

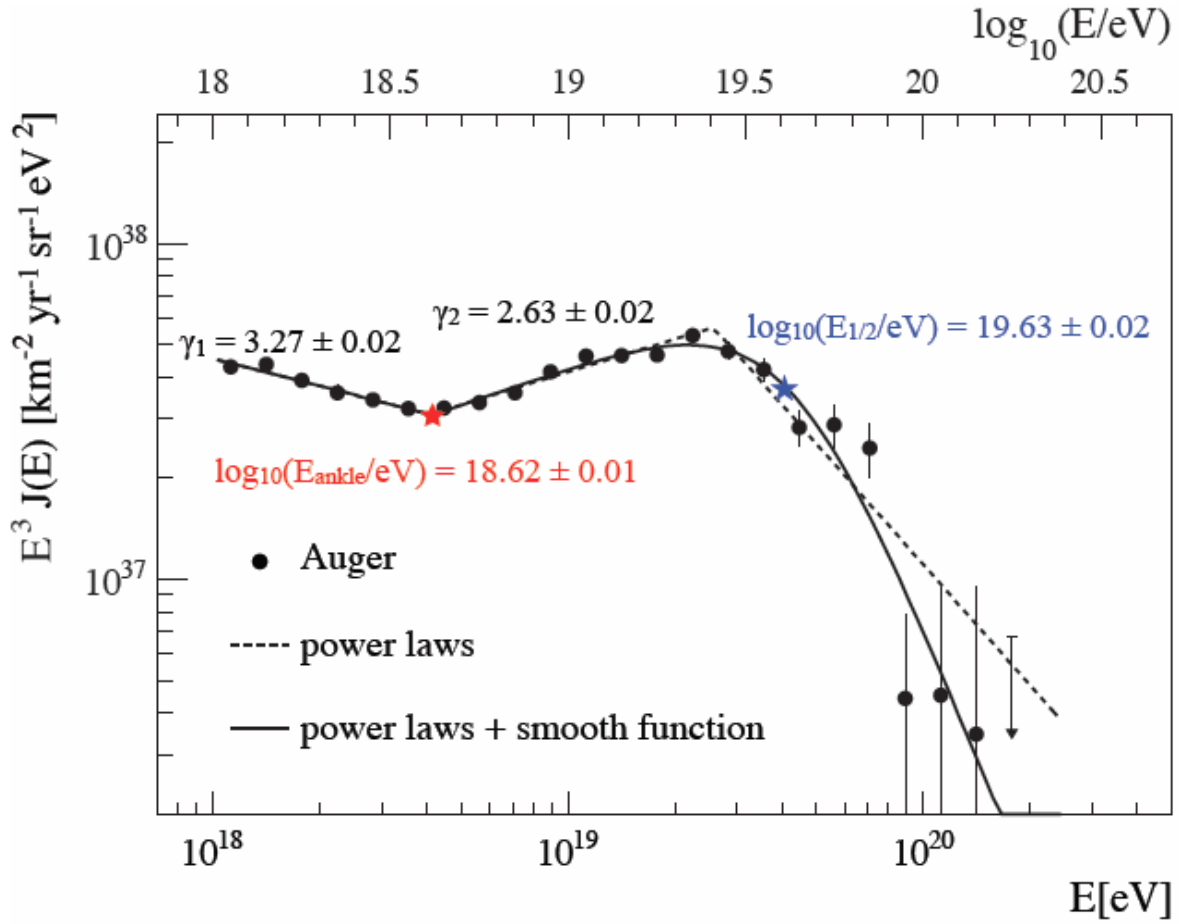
- time-dependent Monte Carlo simulations

- syst. uncertainties ~10% (6%) at 10^{18} eV (10^{19} eV)





The UHECR Spectrum



Combined Spectrum

- Hybrid: accurate energy measurement down to 10^{18} eV
- SD huge statistics ($E > 10^{18.5}$ eV)

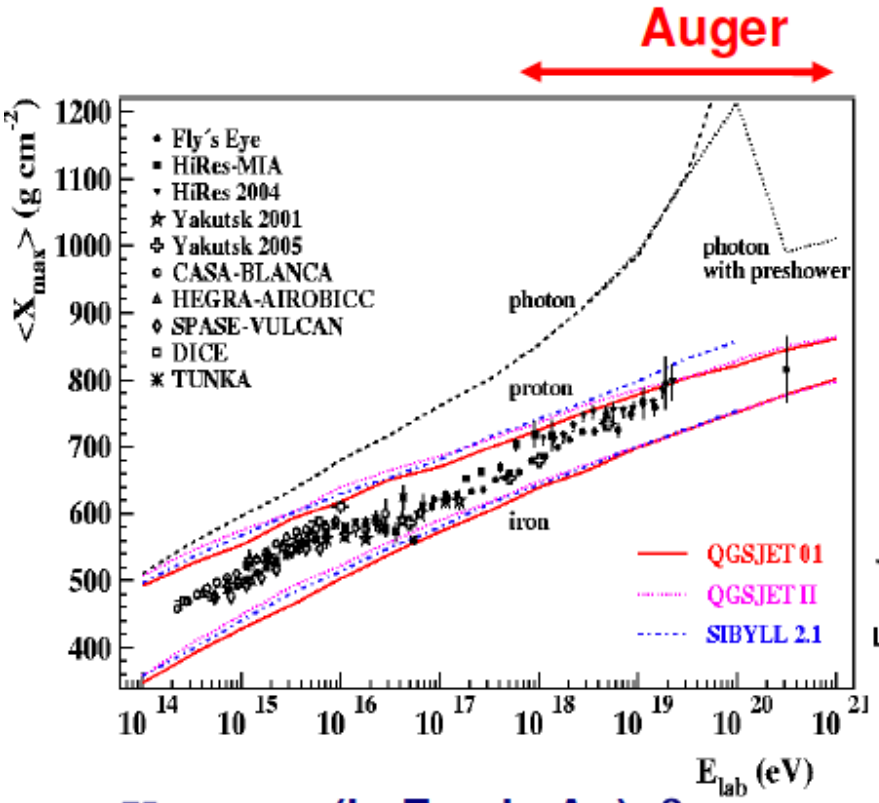
syst. FD energy scale 22%

- fluorescence yield 14%
- FD absolute calibration 9.5%
- invisible energy 4%
- reconstruction 10%
- atmospheric effects 8%

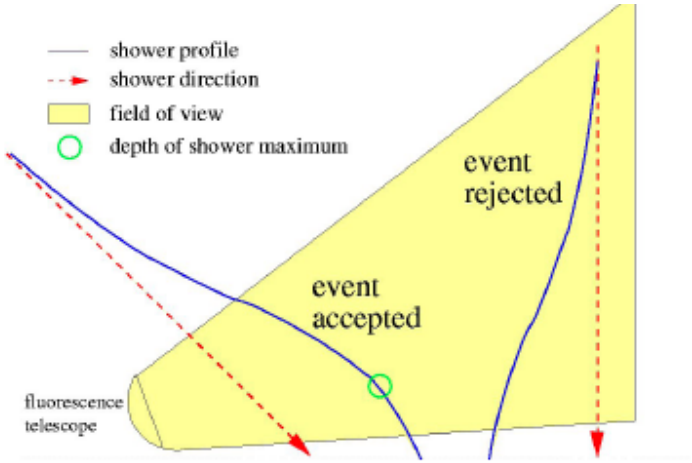
•Ankle: may indicate a change in the origin of UHECR (galactic to extragal. origin)

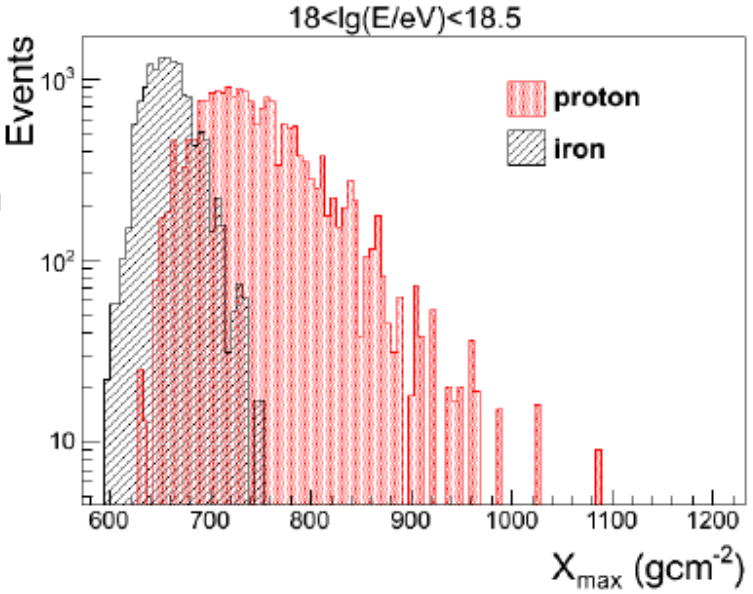
•Flux suppression above $10^{19.5}$ eV found with 20 σ significance (GZK?limit of source?)

The shower observables for composition study:



$$\langle X_{max} \rangle = \alpha(\ln E - \langle \ln A \rangle) + \beta$$

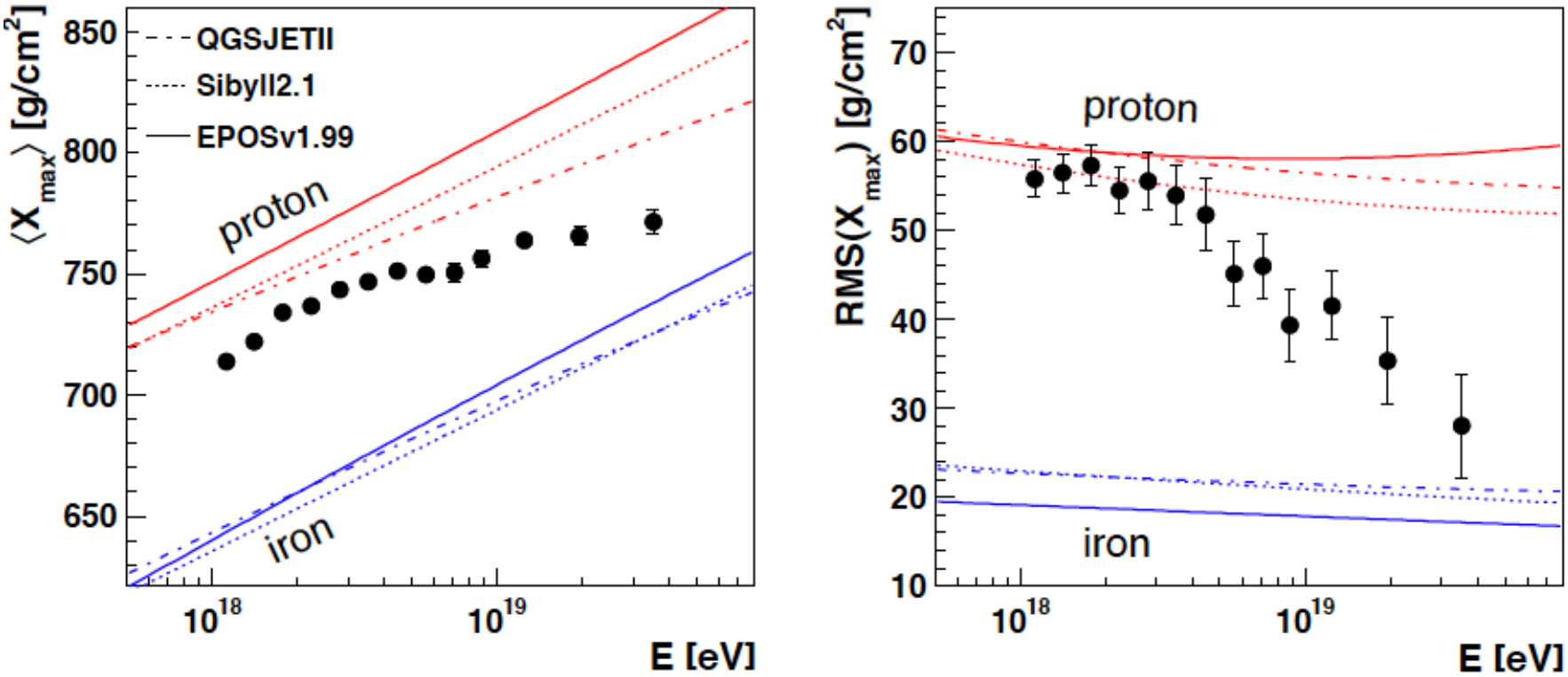




<Xmax> and its RMS
- sensitive to mass composition
- key observables for composition studies

The composition results:

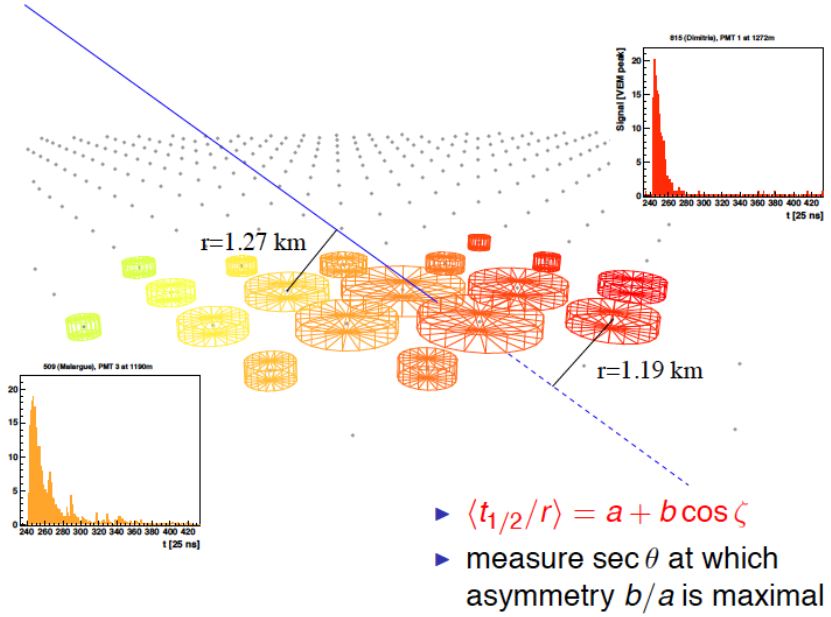
The total syst. uncertainty on <Xmax > is 13 g/cm^2 at high energy (calibration, the atmospheric data, the reconstruction and the event selection).



Change in composition of cosmic rays from light to heavy primaries using hadronic interaction model which are based on the extrapolation of accelerator data at low energies.

The air shower observables for composition study in SD:

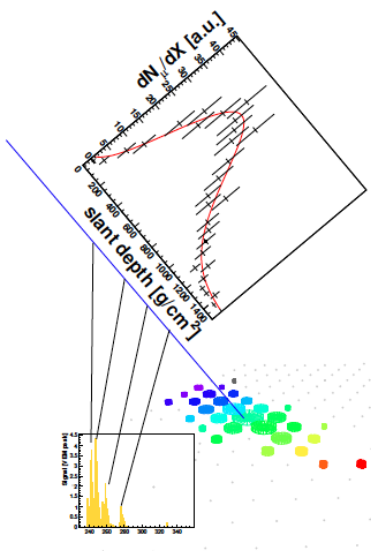
Rise Time Asymmetry



- $\langle t_{1/2}/r \rangle = a + b\cos\zeta$
- measure $\sec\theta$ at which asymmetry b/a is maximal

Dova et al., APP31 (2009), 312

Muon Production Depth



- muon-rich stations:
  - events with zenith angle 55-65 deg.
  - stations with core distance >1.8 km
- projection of signal time traces to axis
- sum up stations

→ distribution of muon production heights

- distance to slant depth conversion
- fit with Gaisser-Hillas

→ maximum at $X^{\mu}_{\max}$

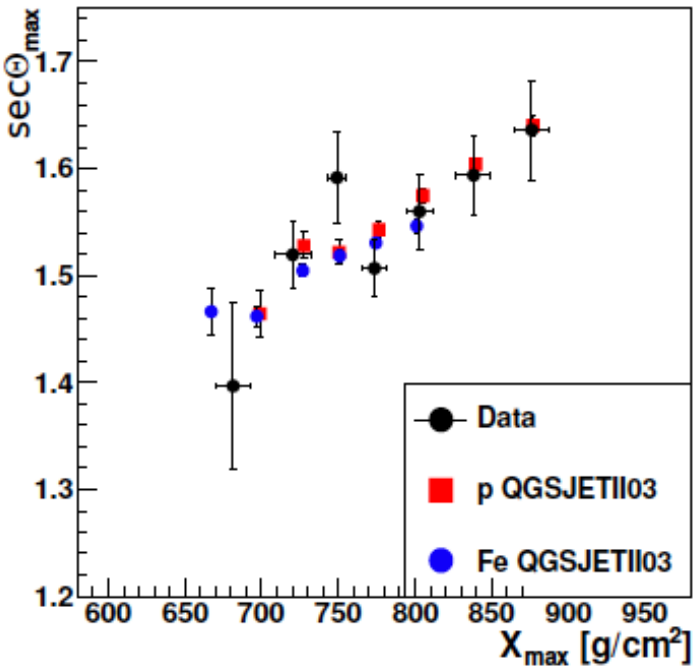
Cazon et al., APP21 (2004), 71

SD can not directly observe the Xmax muon content, muon production depth , azimuthal asymmetry of the signal rise time) are related to the mass of the primary particle and to the shower development.

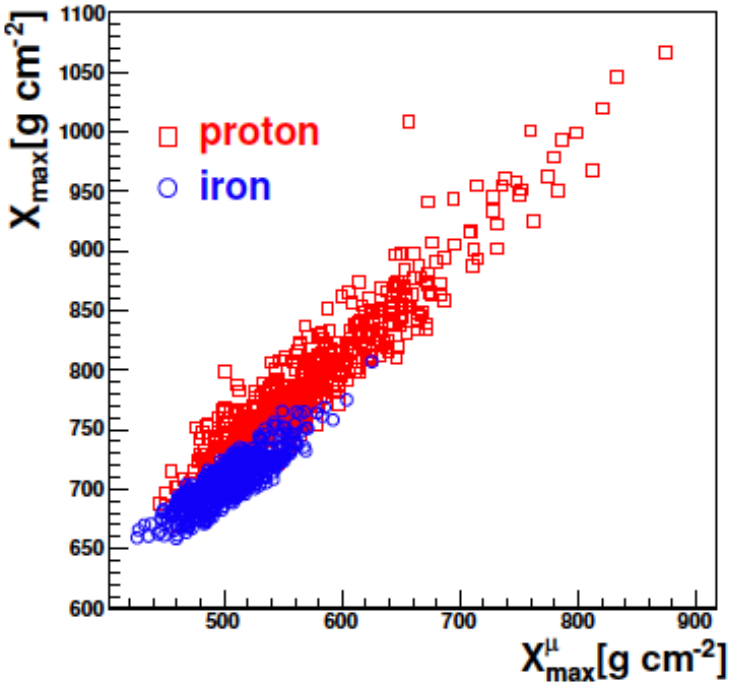
The mass sensitive observables from SD can provide complementary information's, with independent statistical uncertainties and higher statistics of events.

The comparing the SD and FD composition observable

rise time asymmetry

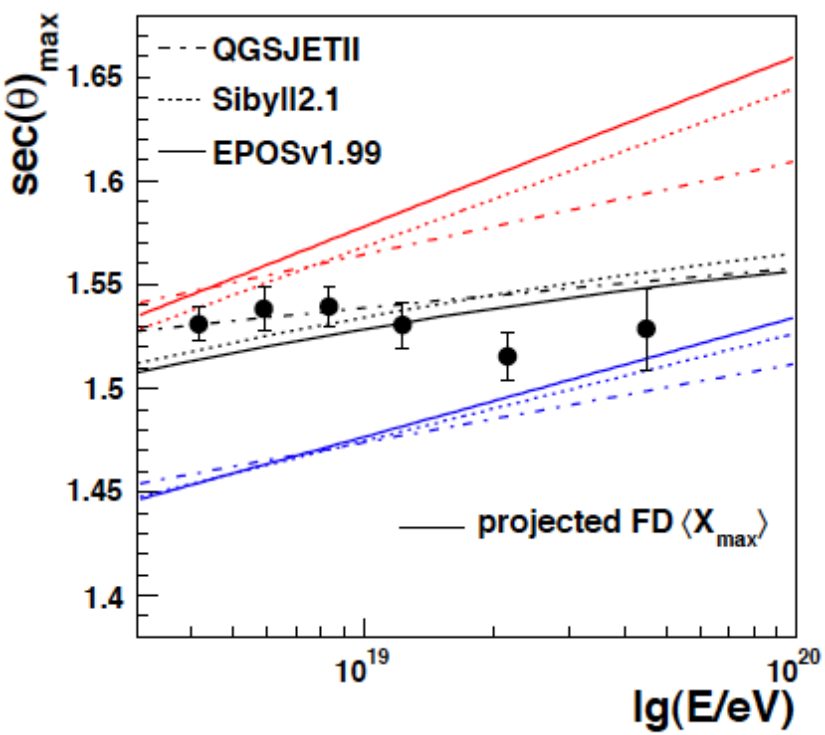


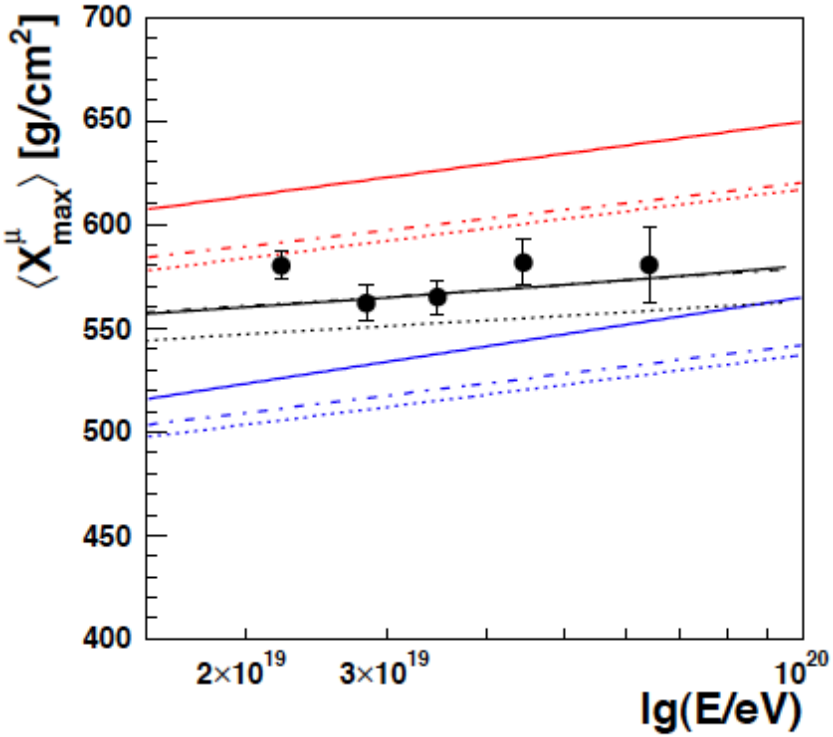
muon production depth



→ estimators of the longitudinal air shower development

The composition results form the SD:



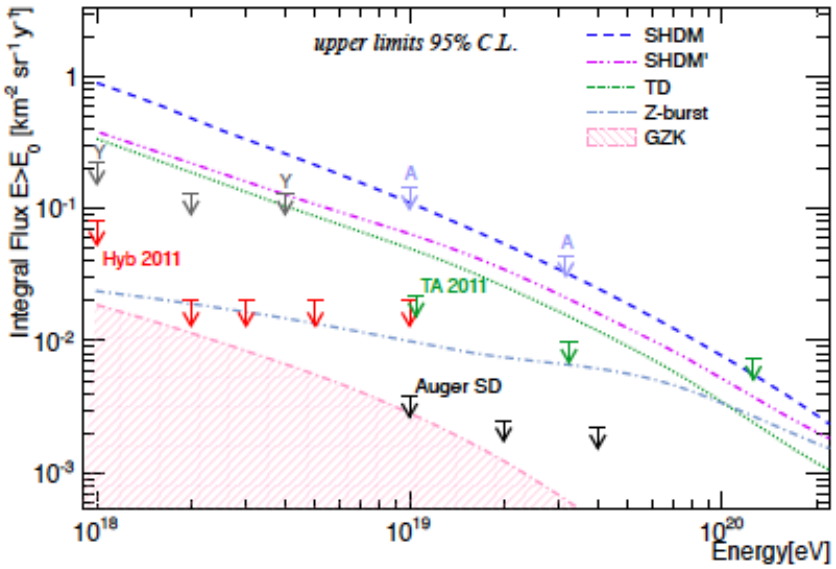


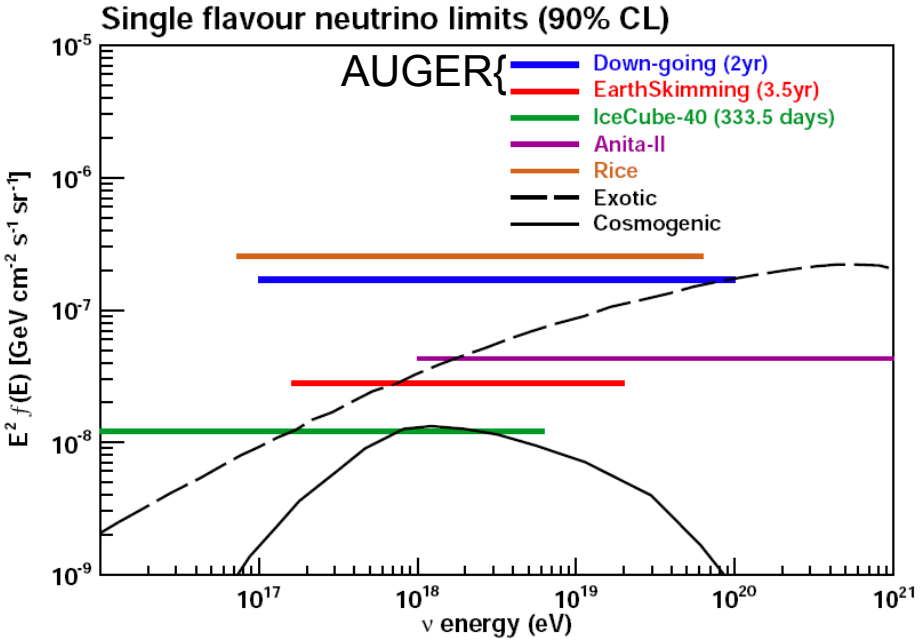
$\sigma(\text{syst.}) \approx 0.01$

$\sigma(\text{syst.}) \approx 15\ \text{g/cm}^2$

The SD and FD composition observable give the issue of a change in air shower composition.

Composition: Photons? Neutrino?



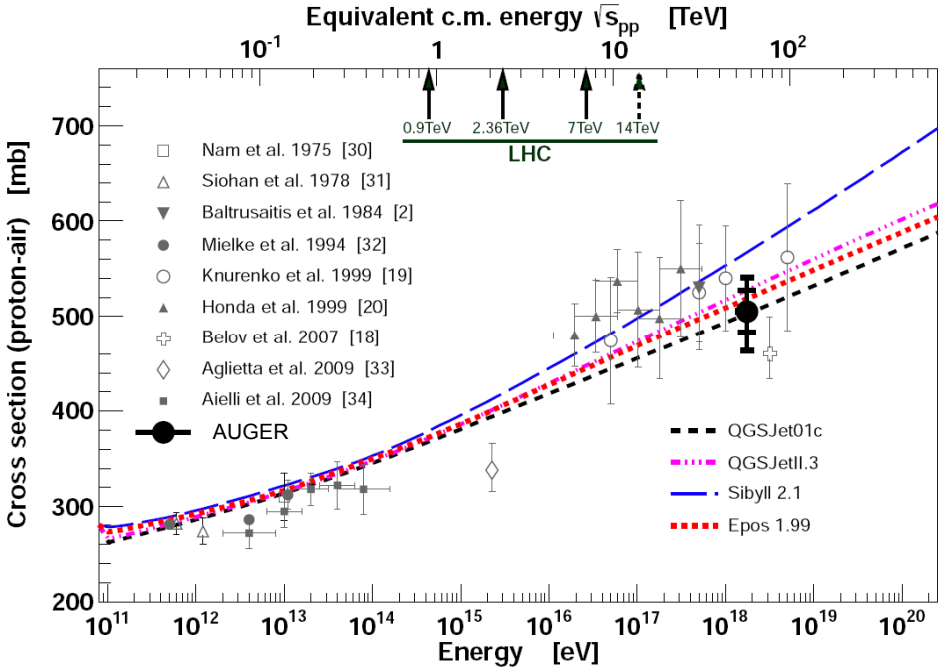


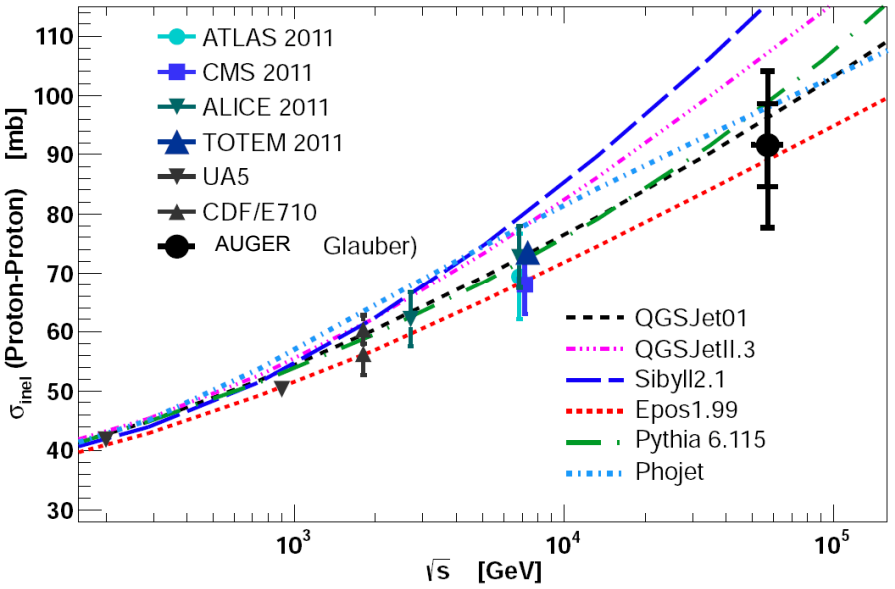
No photon candidate in Auger events.

No neutrino candidate in Auger events.

Cross sections measurements:

The tail of the *X*max distribution is sensitive to the proton-air cross-section.





$$\sigma_{\text{p-air}} = (505 \pm 22_{\text{stat}} (^{+28}_{-36})_{\text{syst}})\ \text{mb}$$

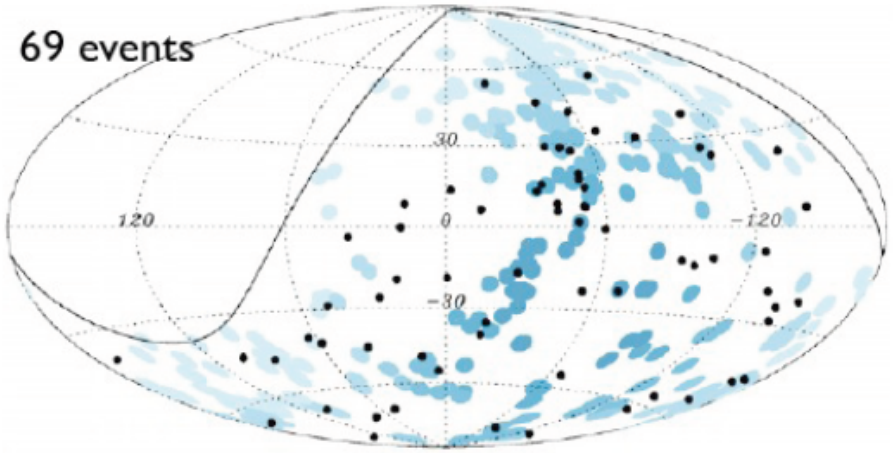
$$\sigma_{pp}^{\text{tot}} = \left[133 \pm 13(\text{stat}) \, ^{+17}_{-20}(\text{sys}) \pm 16(\text{Glauber})\right]\ \text{mb}$$

$$< E > \sim 1.7\ \text{EeV} \qquad \sqrt{s} = 57\ \text{TeV} \pm 0.3_{\text{stat}} \pm 6_{\text{sys}}$$

Summary

- The Auger results in the last few year has given us the possibility to investigate the origin of the UHECRs.
- Future proposed improvements of the detectors can give us the possibility to identify the origin of the UHECRs.

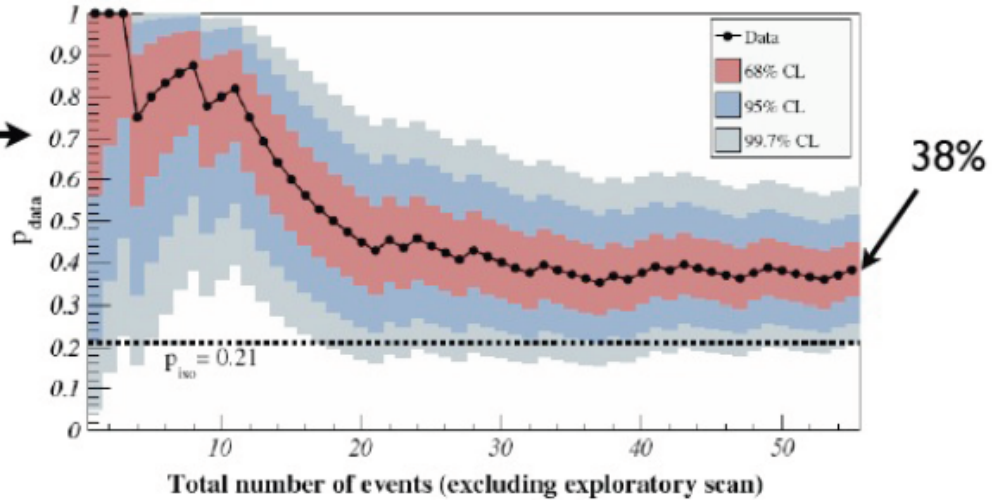
Arrival directions



Parameters defined *a priori*:

$$E_{min} = 55 \text{ EeV}$$
$$\psi = 3.1 \text{ deg}$$
$$d_{max} = 75 \text{ Mpc}$$

Fraction of events correlating with nearby VCV AGN



Astropart. Phys. 2010, 34: 314