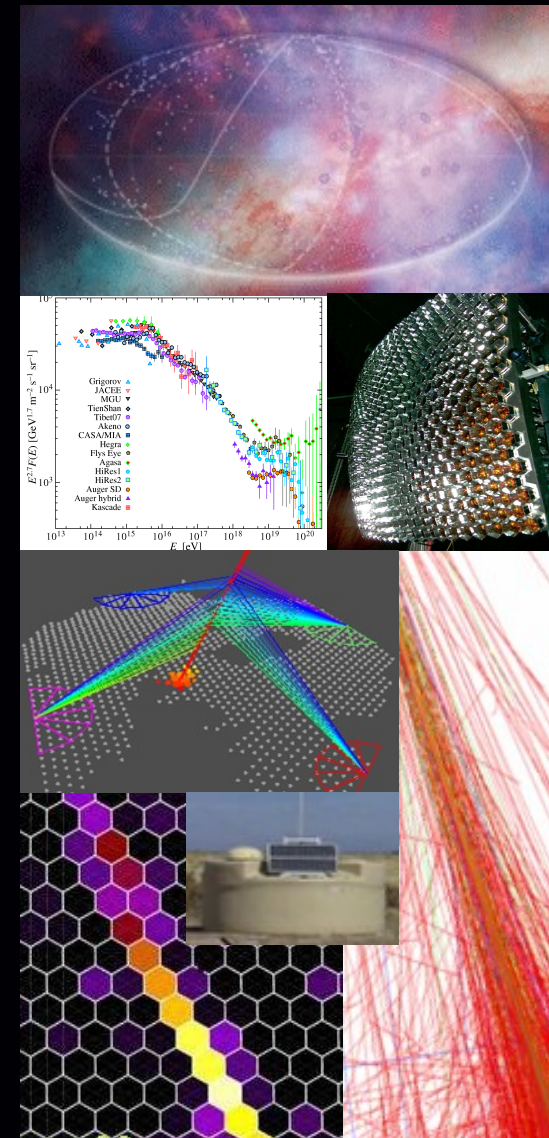


PIERRE
AUGER
OBSERVATORY

Measurement of the UHE Cosmic Ray spectrum with the Pierre Auger Observatory

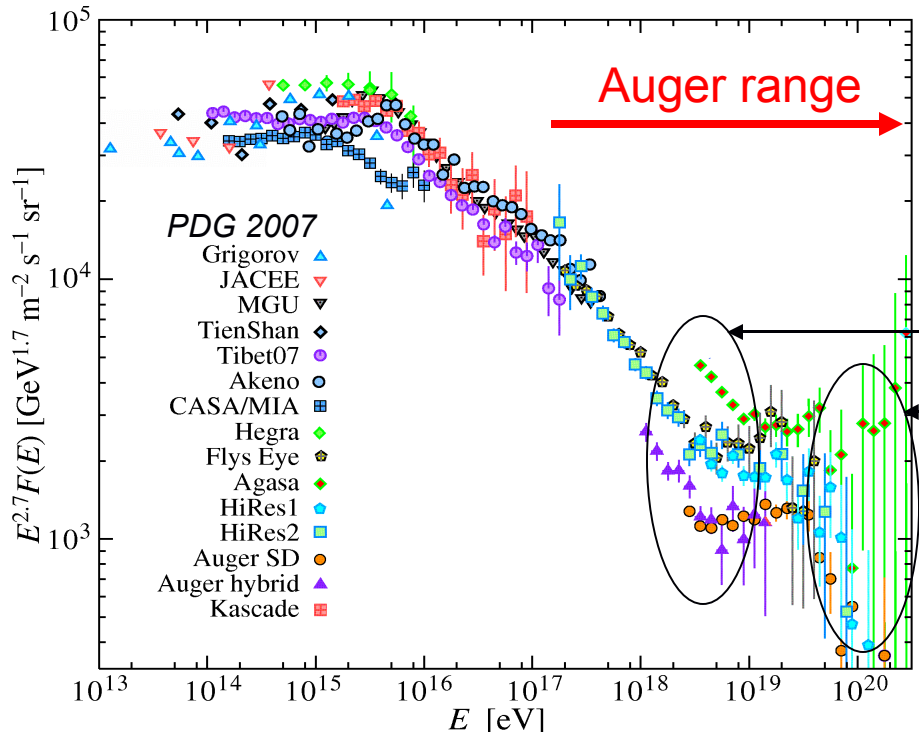
Carla Bleve*, for the Pierre Auger Collaboration

* School of Physics and Astronomy, University of Leeds



UNIVERSITY OF LEEDS

The UHE Cosmic Ray Spectrum



Changes in the power law behaviour indicate different CR sources and/or particle physics processes

What is the **ankle** ?

GZK cutoff ?
CR astronomy ?

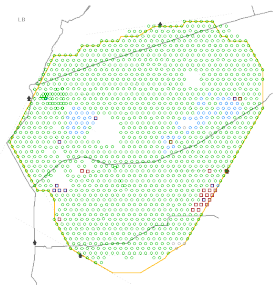
Particle physics at energies beyond LHC limits?

Experimental issues:

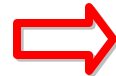
- low fluxes
- Systematic model dependence of the SD-only energy reconstruction (AGASA) and of the FD aperture (HiRes), both based on Monte Carlo simulations

Measuring the spectrum with the Pierre Auger Observatory

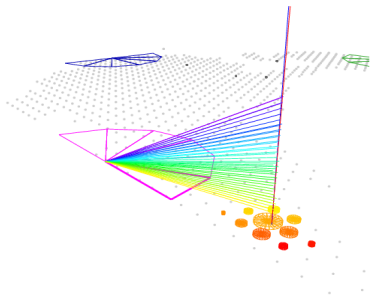
The Auger Observatory is designed to measure the UHECR spectrum with unprecedented precision:



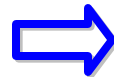
3000 km² SD



statistics at the highest energy end of the spectrum



Hybrid technique



energy scale from FD calorimetric measurement

The spectral measurements:

- **high statistics SD spectrum** ($\theta < 60^\circ$)
- **inclined SD spectrum** ($60^\circ < \theta < 80^\circ$)
- **hybrid spectrum**

“the” spectrum

← increase statistics

← extension at lower energies

The SD spectrum ingredients

- Energy reconstruction

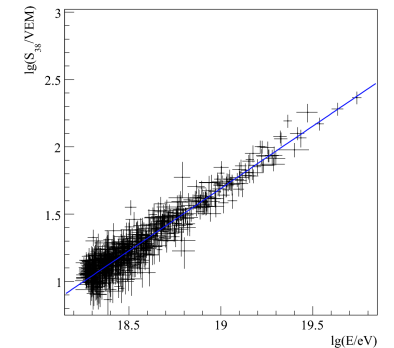
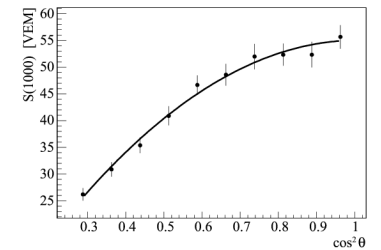
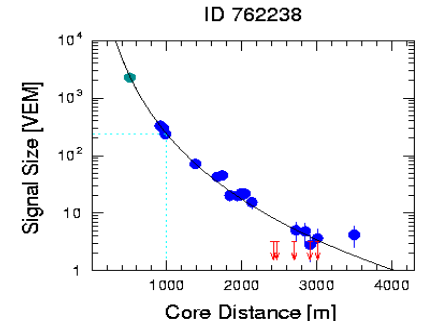
- ✓ Estimator of the event energy ($\theta < 60^\circ$) **S(1000)**

- ✓ Atmospheric attenuation **CIC**

- ✓ Establish the energy scale **hybrid calibration**

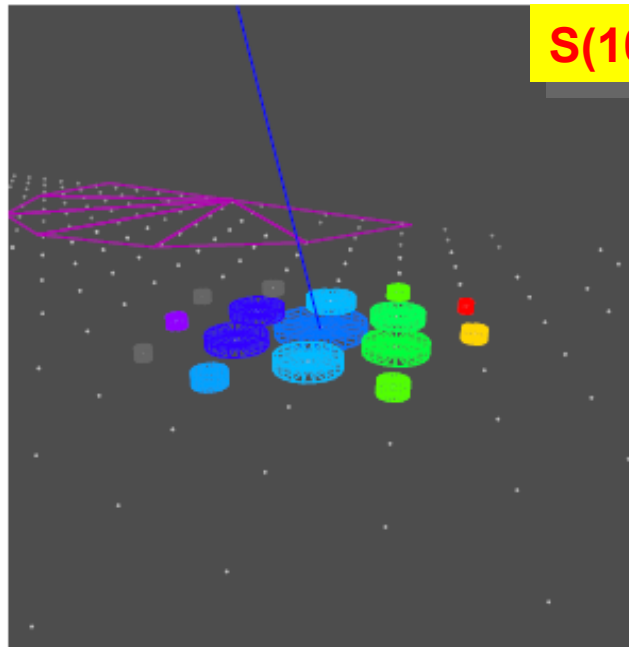
- Exposure

- ✓ 100% efficiency for $E > 3 \times 10^{18}$ eV **pure geometry**



Event energy estimator: $S(1000)$

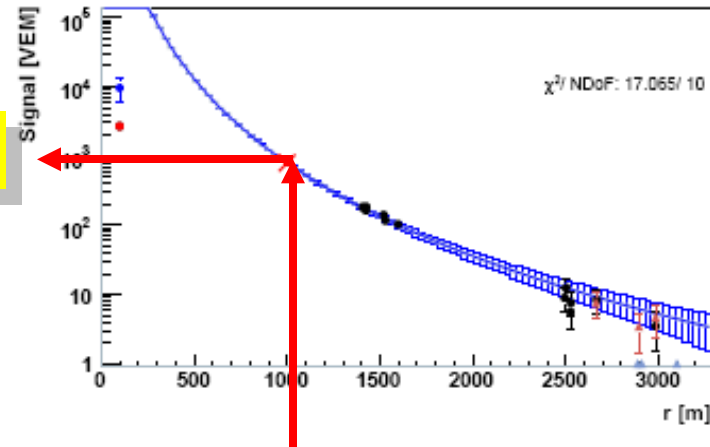
- The direction of the primary is reconstructed through the arrival time of the shower front
- The lateral distribution of particles is sampled by the signal size in each tank



$\vartheta = 14^\circ$

$E \sim 10^{20}$ eV

$S(1000)$



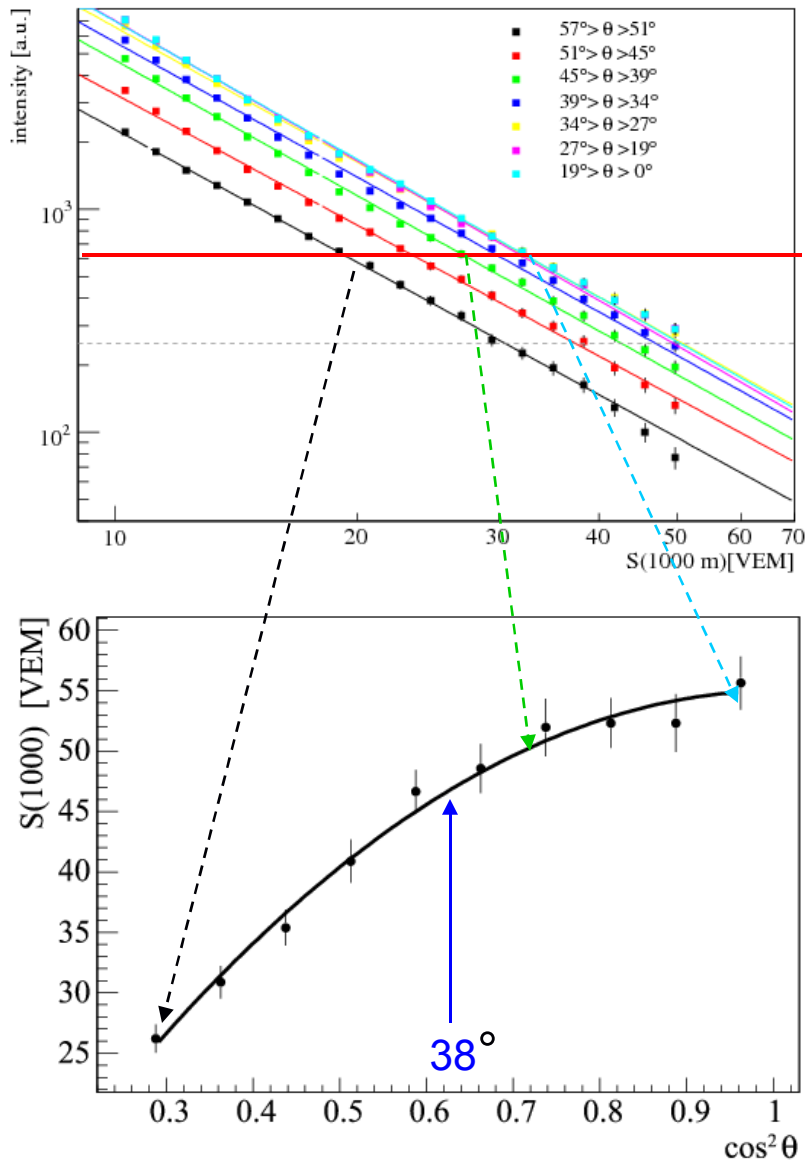
Standard SD energy estimator

$S(R)$

- optimal $R = 1000$ m
- $S(1000) \sim E$ but θ dependent

Uncertainty $\sim 10\%$ above 10^{19} eV

Atmospheric attenuation: integral Constant Intensity Cut



The CR flux on the top of the atmosphere does not depend on the local zenith

Constant intensity \equiv Fixed Energy

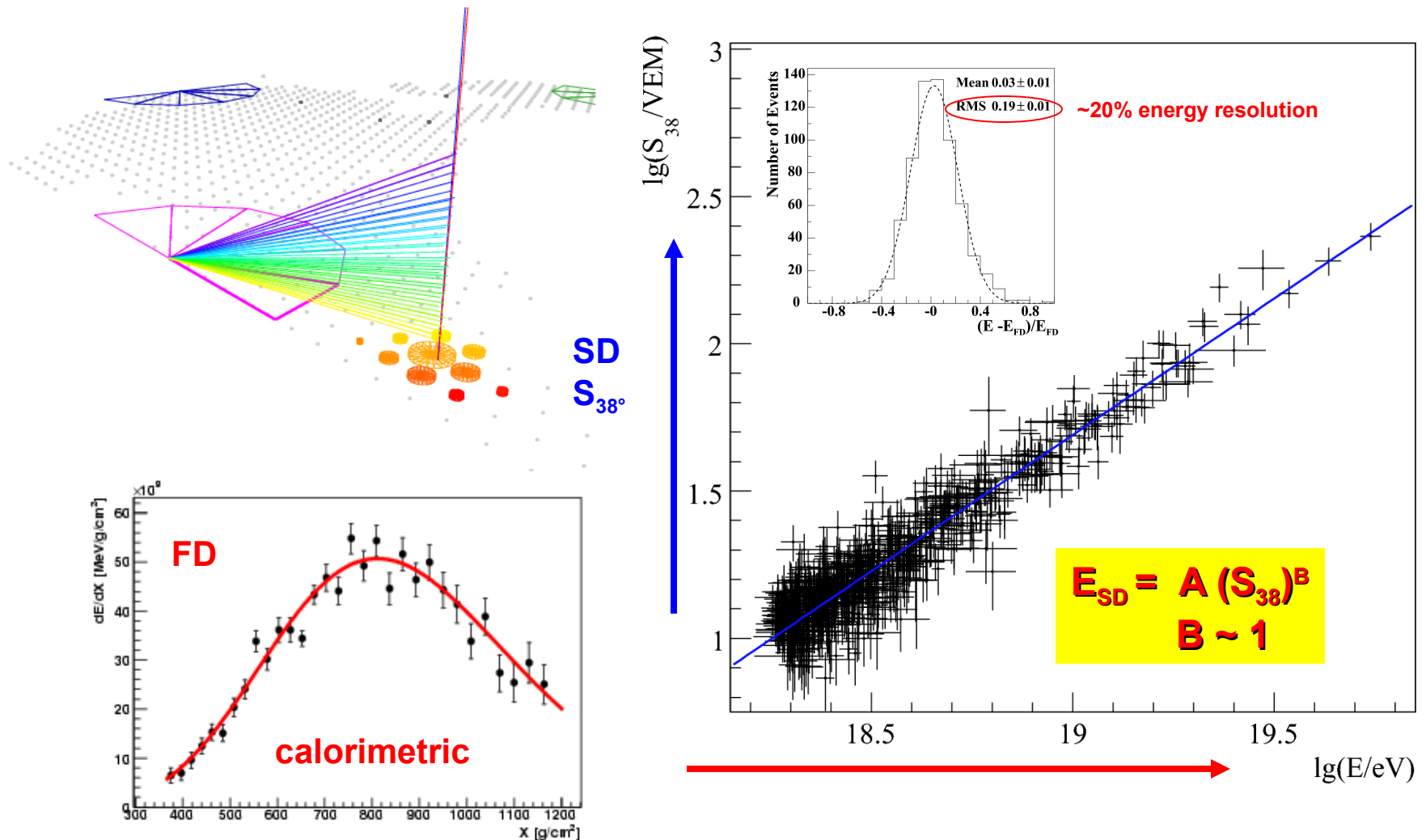
Given a measured $S(1000)(\theta)$

S_{38°

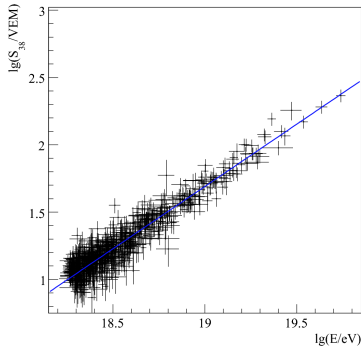
38° is the median zenith angle of events with $\theta < 60^\circ$

Energy scale: hybrid calibration

661 high quality hybrids: independent reconstruction with SD and FD



Systematic uncertainties on the energy scale

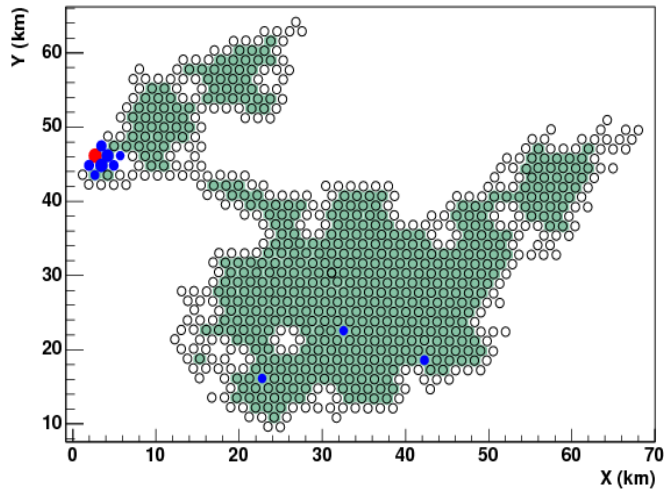


- Energy uncertainty from the calibration procedure:
 - 7% at 10^{19} eV
 - 15% at 10^{20} eV
- Improves with hybrid statistics

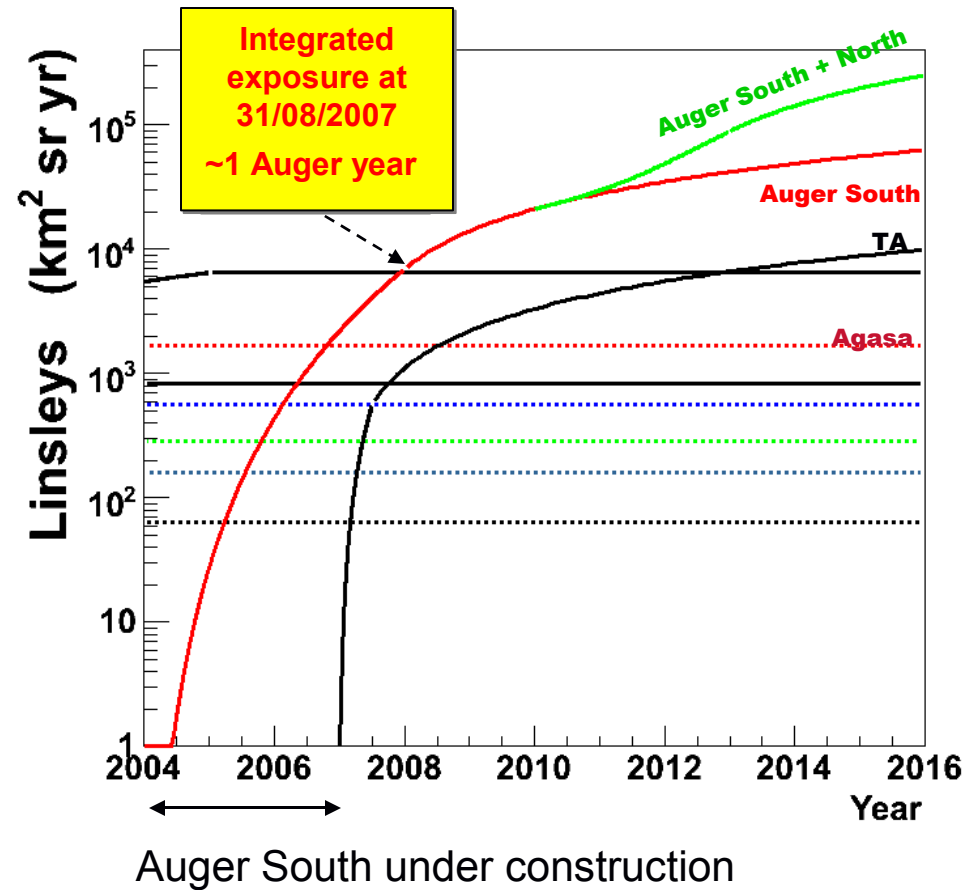
- and from the FD energy measurement:

Source	Systematic uncertainty	
Fluorescence yield	14%	← Nagano + AIRFLY
P,T and humidity effects on yield	7%	
Calibration	9.5%	← Calibration source, laser
Atmosphere	4%	
Reconstruction	10%	← Optical spot, lateral Ch.kov distrib.
Invisible energy	4%	
TOTAL	22%	

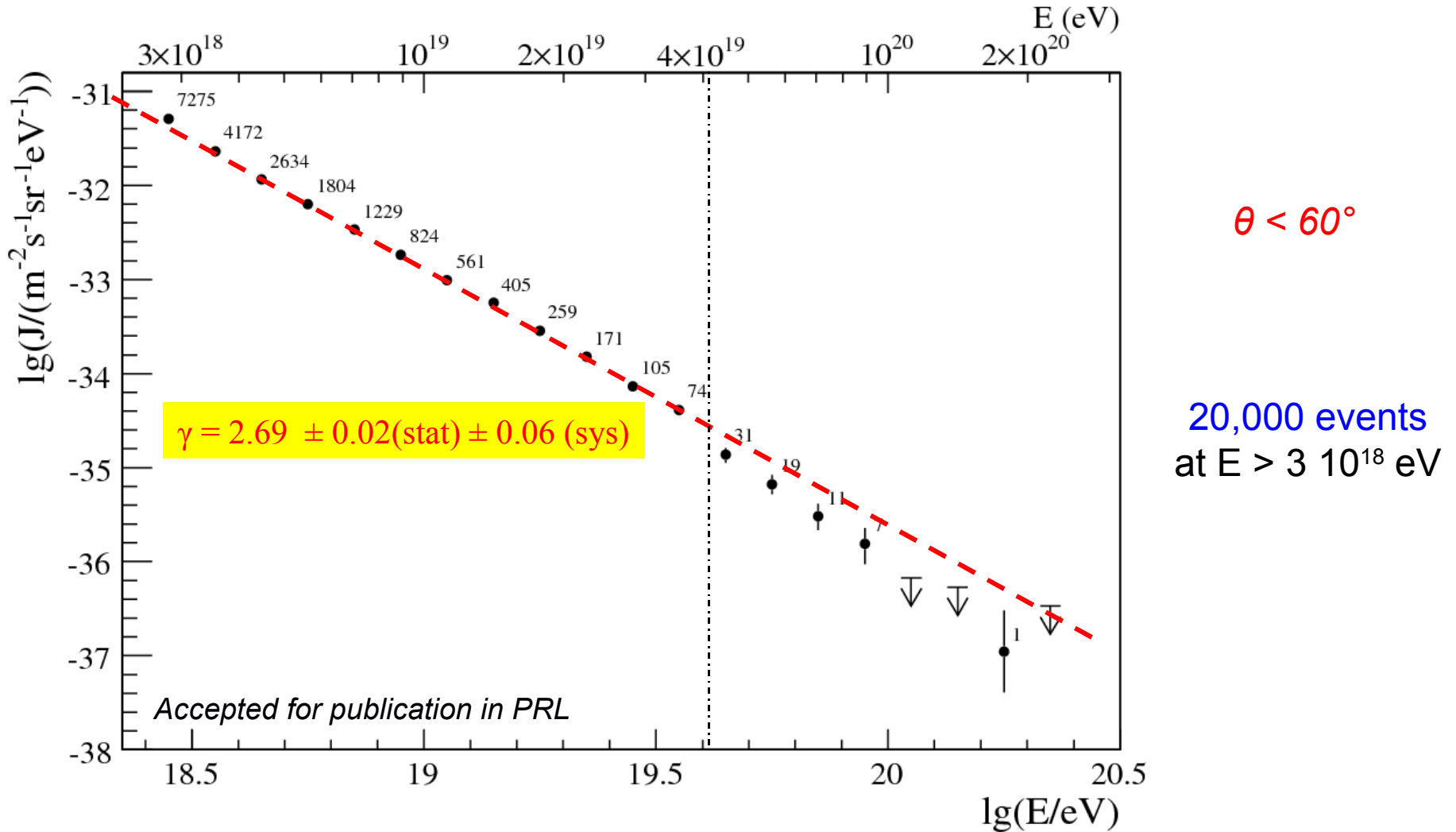
Detection efficiency
100%
 for $E > 3 \cdot 10^{18}$ eV



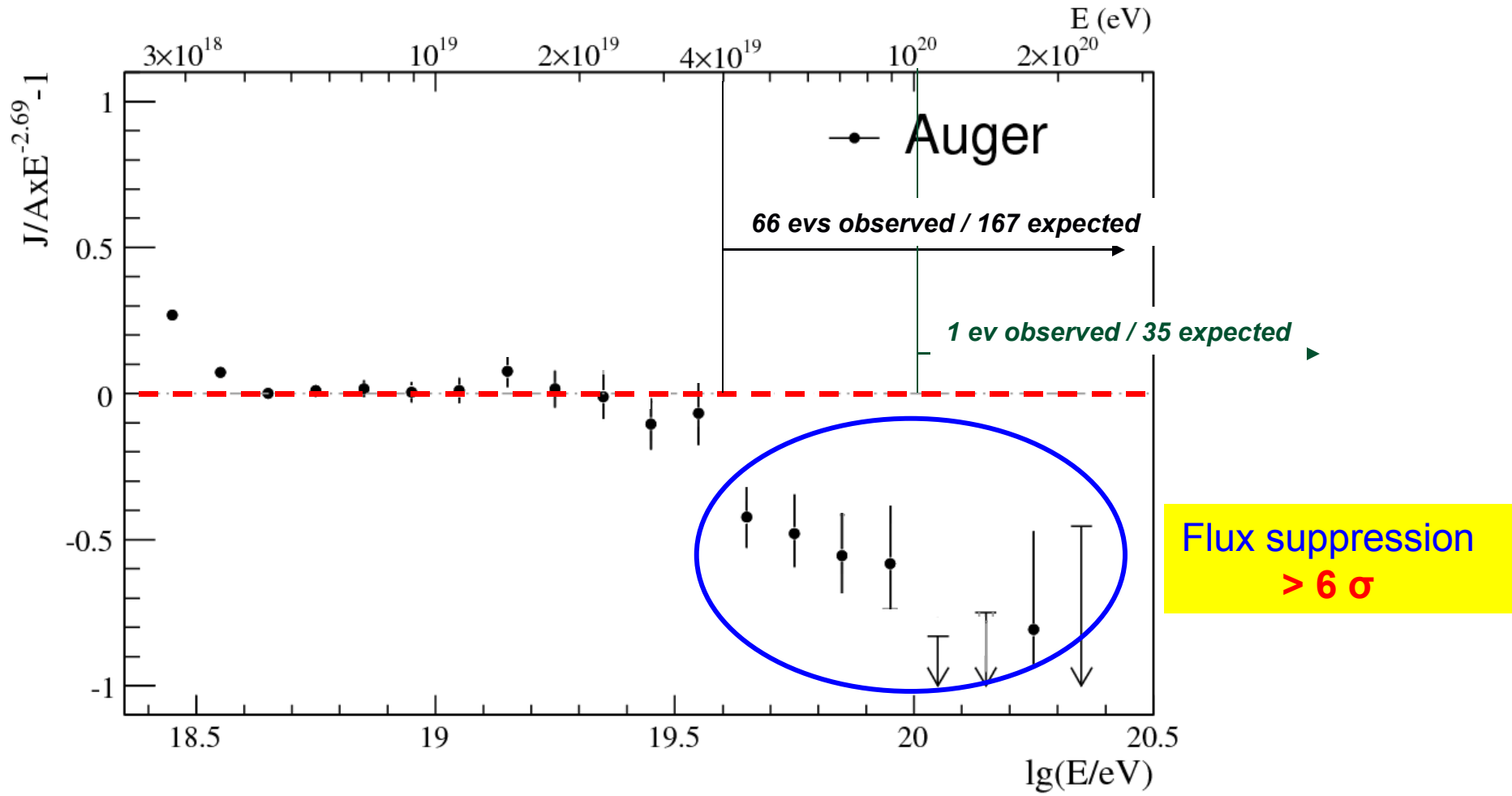
At a given time exposure is proportional to the active area



Integrated exposure **7000 km² sr yr** (1 year full AUGER, AGASA x 4)

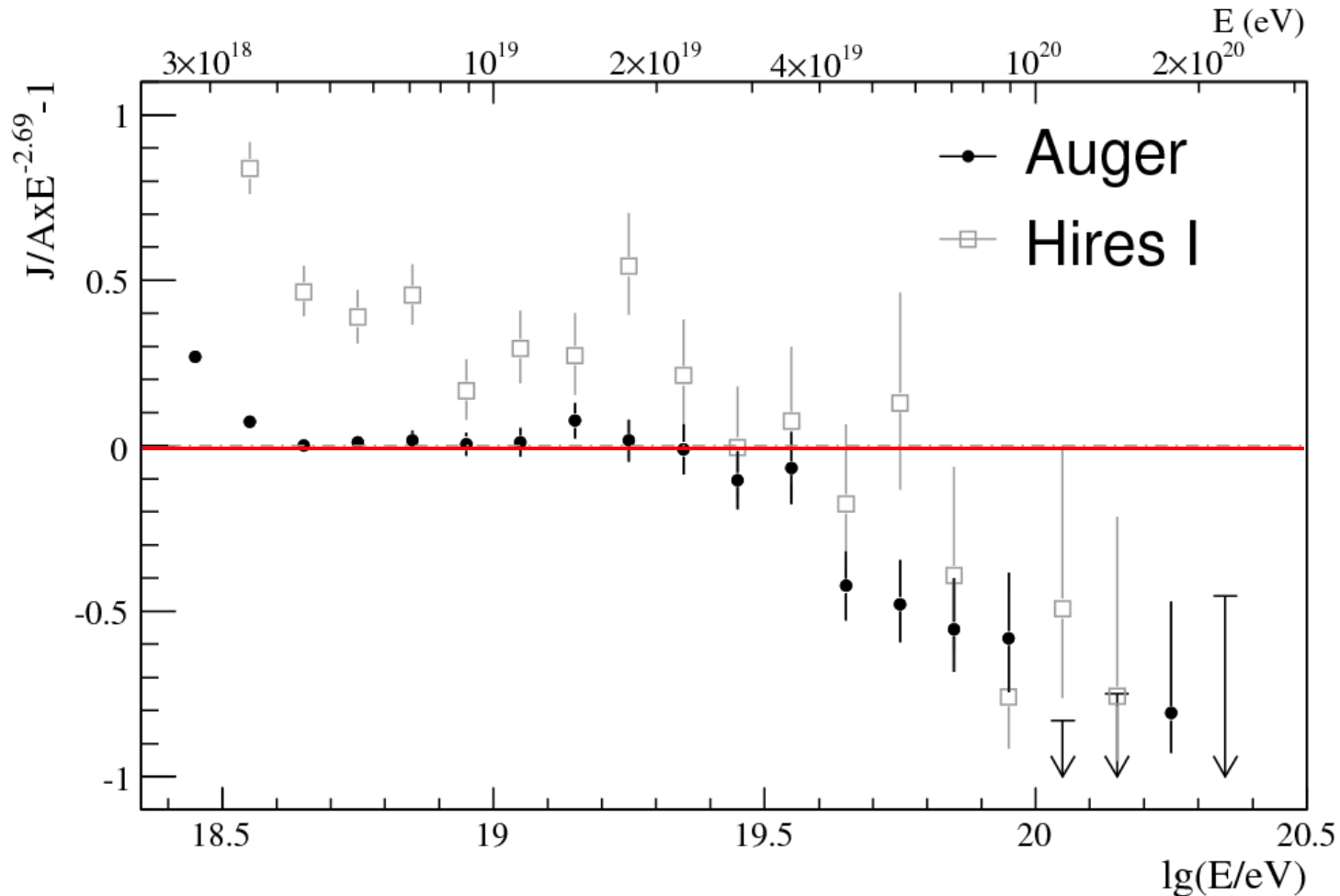


Evidence of flux suppression

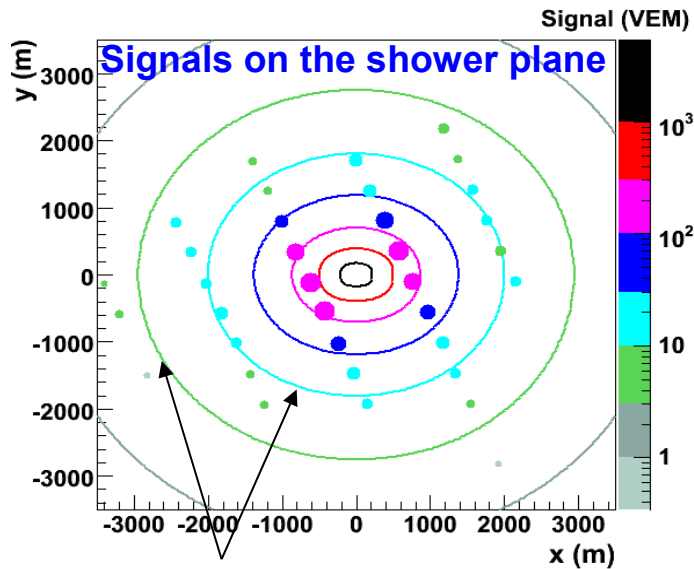
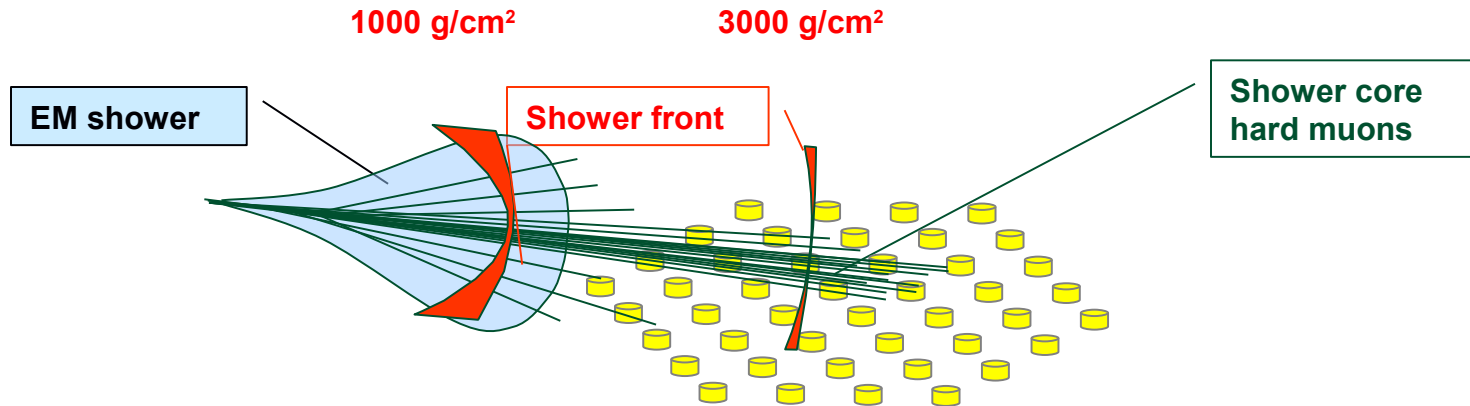


Not affected by the systematic uncertainty on the energy scale

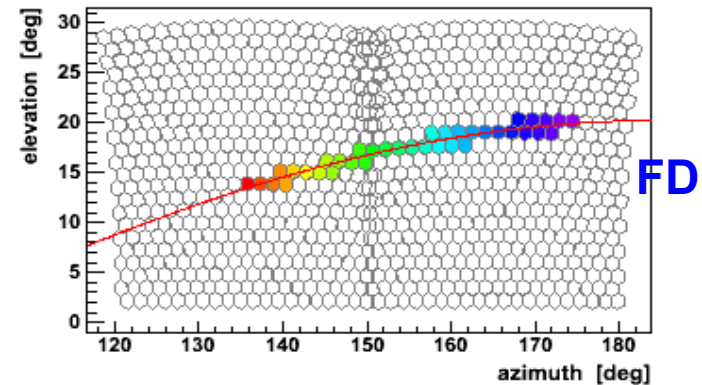
Auger and HiRes



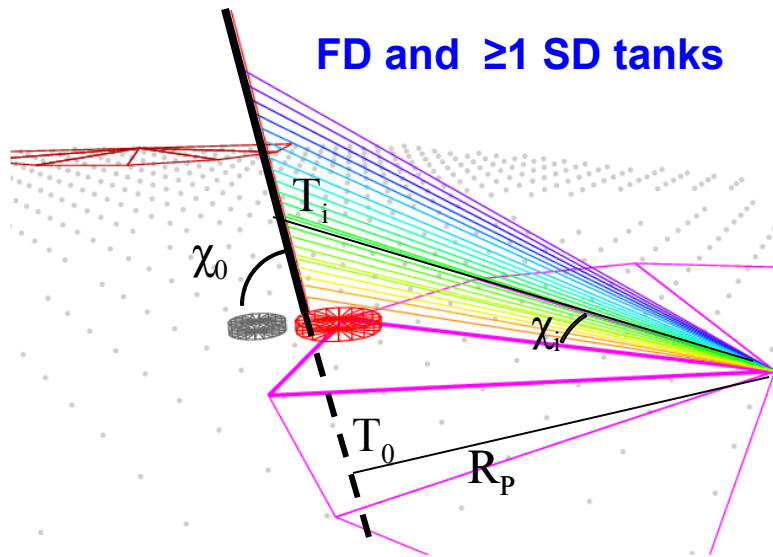
Compatible if a $\sim 15\%$ relative shift in the energy scale is applied
(consistent with the experiments systematic uncertainties)



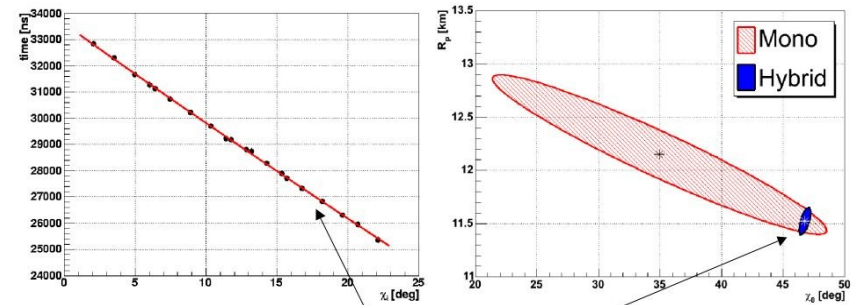
Signal levels from the **MC** muon map



$\text{Signal} \sim N_{19} \cdot \rho(x,y) \longleftrightarrow E_{\text{FD}}$
Hybrid calibration



Hybrid vs Monocular



\approx line but
3 free parameters

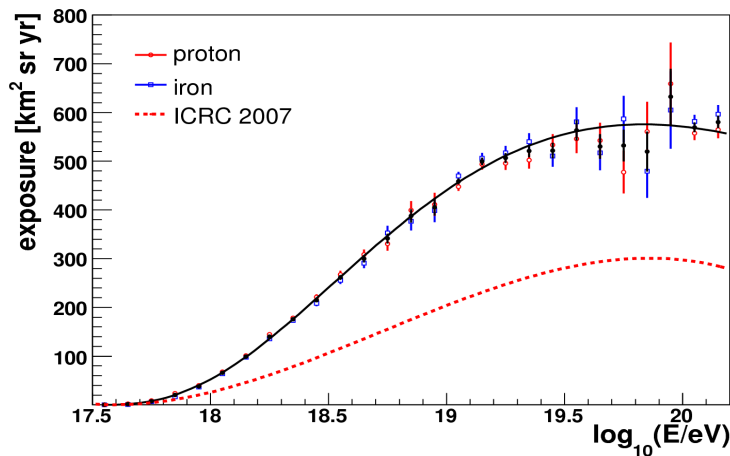
T_0 from tank!

$$t(\chi) = T_0 + \frac{R_p}{c} \tan \left[\frac{(\chi_0 - \chi)}{2} \right]$$

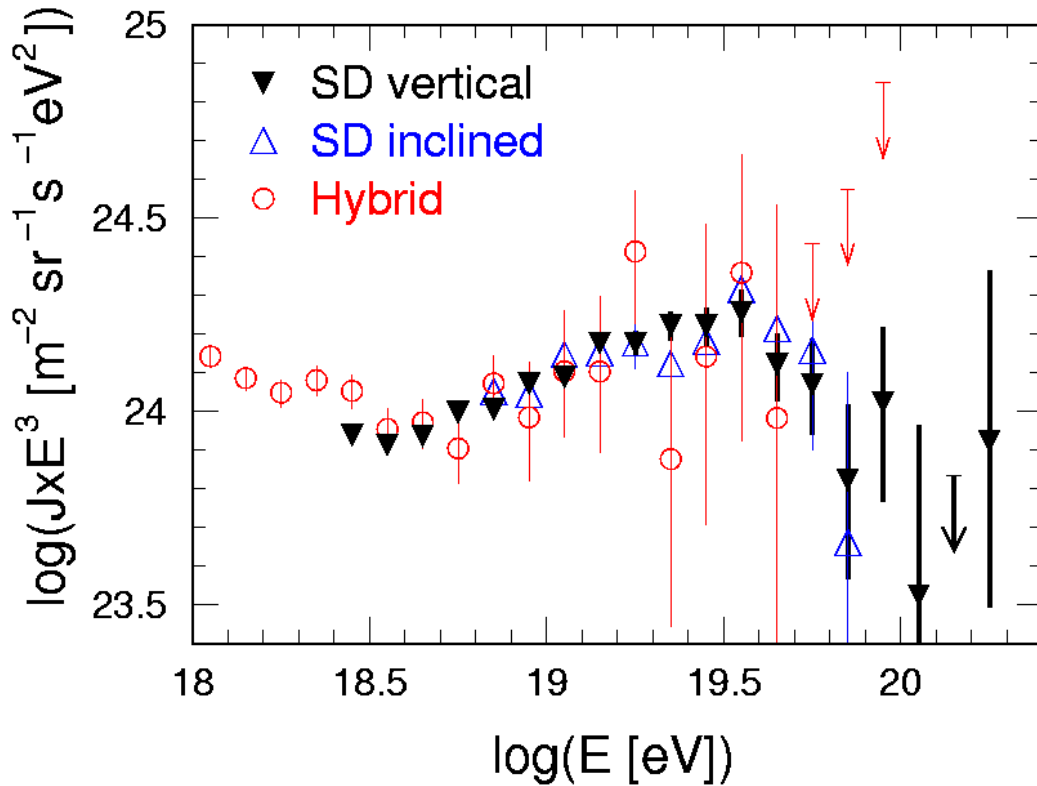
The time information from 1 SD tank improves dramatically the geometry resolution

The exposure

- is strongly energy dependent
- it is determined with detailed MC simulations (including FD uptime, atmospheric conditions etc.)



The Auger measurements of the spectrum compared ICRC07

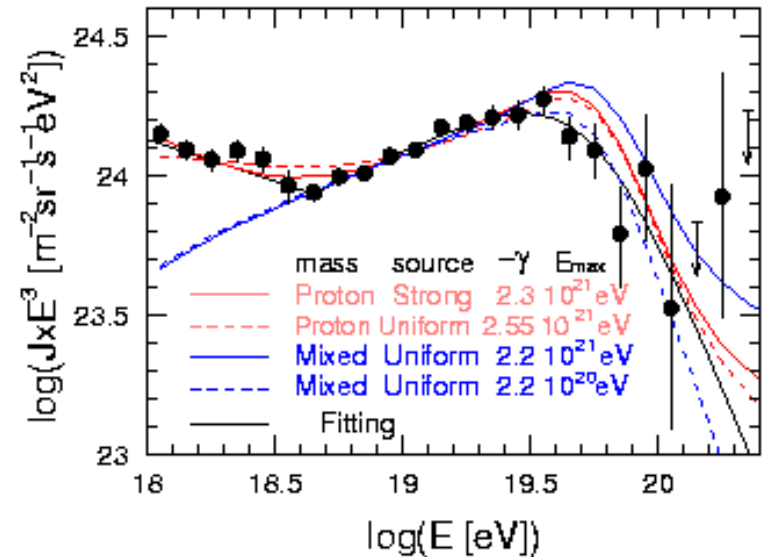


(data Jan 2004 – Feb 2007)

Consistency of the 3 measurements done with different techniques, data sets and exposures



Combined spectrum
 allows for comparisons with model predictions on a wide energy range



Summary

- ✓ The Pierre Auger Observatory is designed for the **high precision measurement of the UHECR spectrum**
 - Large SD area → high statistics
 - Hybrid detection → energy scale based on FD calorimetric measurement
- ✓ > 6σ evidence for UHECR **flux suppression at the highest energies**
 - coherent picture with the observed 3σ correlation with nearby sources
 - possible new window in astronomy: CR at extreme energies
- ✓ The **agreement among three different measurements** of the spectrum (SD, inclined, hybrid) proves the quality of the results

Future:

- exposure steadily increasing (statistics x2 the PRL SD in few months)
- combined spectrum with added statistics from inclined and energy range extended to the ankle region (with hybrids)