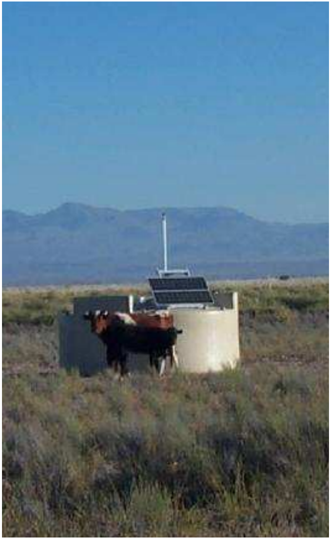
Ultra High Energy Cosmic Rays and the Pierre Auger Observatory

Michael Unger

(Forschungszentrum Karlsruhe)

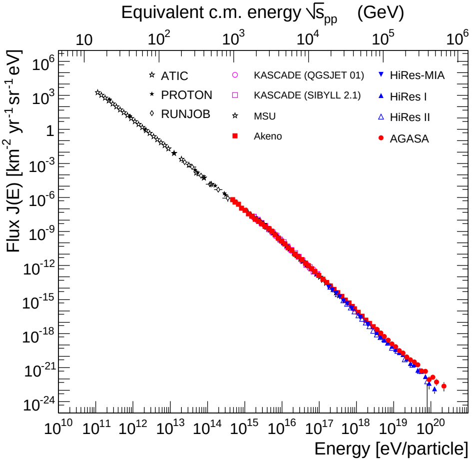
for the Pierre Auger Collaboration

Outline



- Ultra High Energy Cosmic Rays
- The Pierre Auger Observatory
    - Surface Detector
    - Fluorescence Detector
- First Results
    - Energy Spectrum
    - The Galactic Center
    - Photon flux
- Outlook

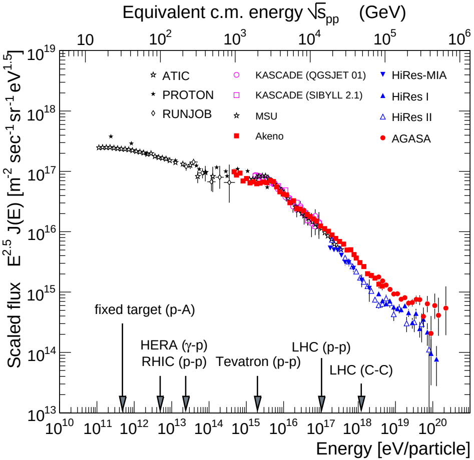
Ultra High Energy Cosmic Rays



(R. Engel, FZK)

- power law $J \propto E^{-\gamma}$
- spectral features at few 10^{15} eV ('knee') and around 10^{18} eV ('ankle')
- particles with $E > 10^{20}$ eV!
- beam energies: $> 10^8$ LHC(p-p)
- center of mass energies: > 10 LHC(p-p)
- low luminosity: 1 particle per km^2 per century

Ultra High Energy Cosmic Rays



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Ultra High Energy Cosmic Rays - Accelerators

- need ILC (35 MV/m)
  L= diameter of Saturn orbit
- alternatively built LHC around Mercury orbit
- astrophysical shock acceleration less efficient...

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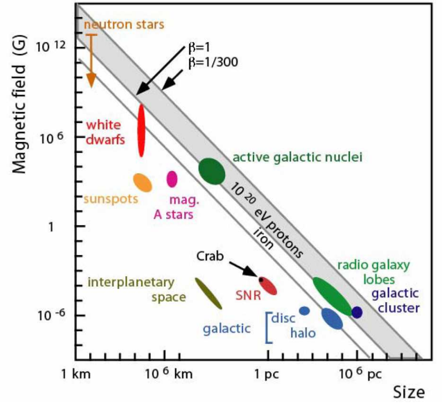

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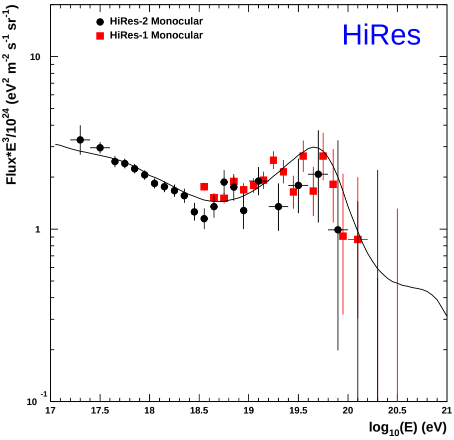
$$E_{\max}/(10^{18}\ \mathrm{eV}) \propto Z \cdot \beta_s \cdot B/(\mu\mathrm{G}) \cdot R/(\mathrm{kpc})$$

β_s: shock front speed [c]
R: size of acceleration region
B: magnetic field

Open Experimental Questions

Does the spectrum of UHECRs show a GZK feature?



- interaction of UHECRs with CMB
- $\rightarrow$ energy loss (Greisen-Zatsepin-Kuzmin cutoff)
- sources are either nearby ($\lesssim$ 50 Mpc) or CRs can not reach us
- available data inconclusive!

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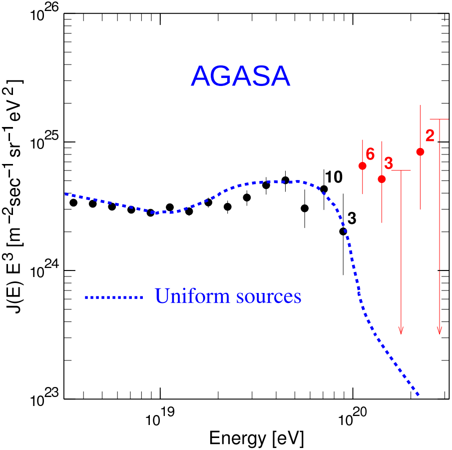

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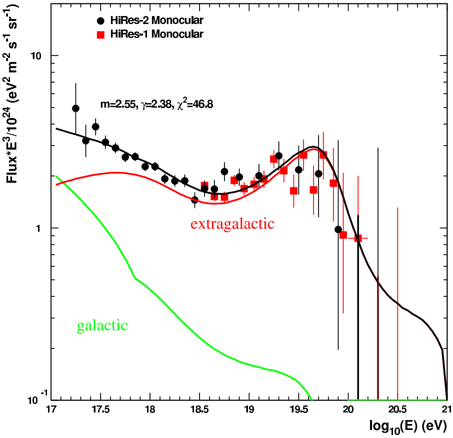
Open Experimental Questions

What is the mass composition of UHECR particles?



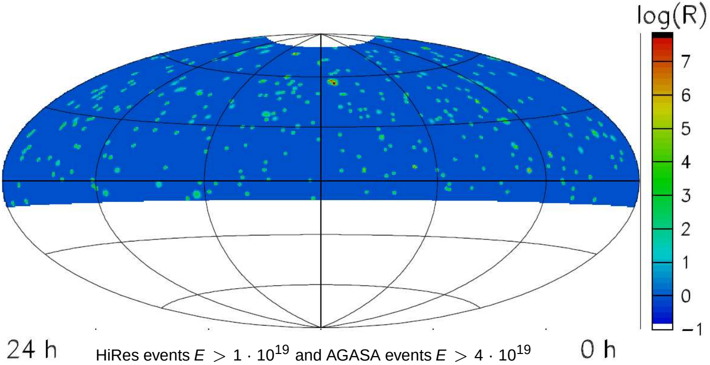
(Bergman et al., Proc 29th ICRC)

- 'ankle' $E=10^{18}$ eV
  $\rightarrow$galactic to extragalactic?
  $\rightarrow$expect transition:
  heavy to light composition
- circumvent GZK cutoff:
  $\rightarrow$heavy relic particles:
  $\rightarrow$expect photons in decay
- super GZK neutrinos

$$p + \gamma_{\rm CMB} \rightarrow n + \pi^+ \searrow \mu + \nu$$

Open Experimental Questions

Can the sources of UHECRs be identified?

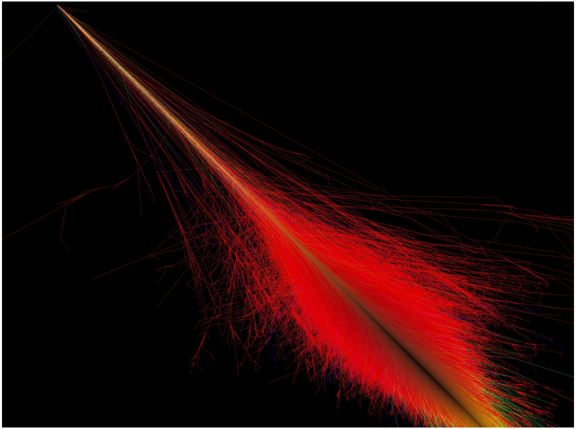


HiRes events $E > 1 \cdot 10^{19}$ and AGASA events $E > 4 \cdot 10^{19}$

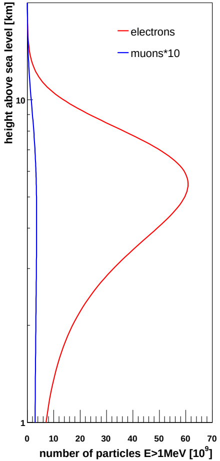
(S. Westerhoff et al., Proc 29th ICRC)

- at low energies: randomization of arrival directions due to irregular galactic and intergalactic magnetic fields
- high energies: particle astronomy?

Air Showers



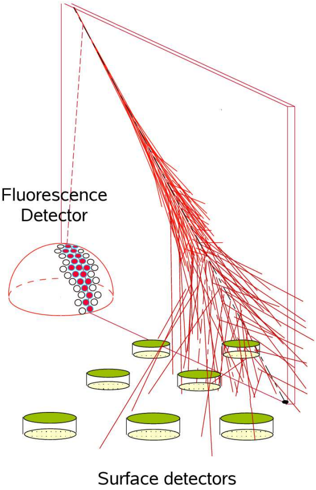
(F. Schmidt, Univ. Leeds)



proton, QGSJET, 60°, 10^{20} eV

- depth of shower maximum $\propto \lg(E/A)$
- integral $\rightarrow E$

Air Showers - Experimental Techniques



Fluorescence detectors:

- energy deposit in atmosphere
  $\rightarrow$ excitation of nitrogen
  $\rightarrow$ emission of fluorescence light
- observe longitudinal shower development

Surface detectors:

- particle detector array at ground
- sample lateral particle densities

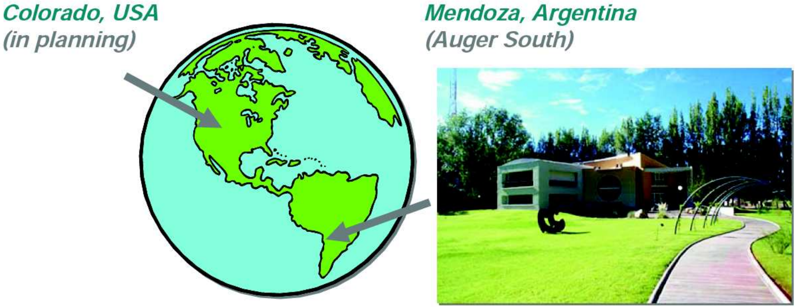
Air Showers - Experimental Techniques

surface detectors (e.g. AGASA)	**fluorescence detectors** (e.g. HiRes)
⊕ 100% duty cycle	⊖ 10-15% duty cycle (clear, moonless nights)
⊕ acceptance = geometric	⊖ acceptance depends on distance and atmosphere
⊖ only last stage of shower development observed	⊕ full observation of longitudinal shower development
⊖ energy scale model dependent	⊕ (almost) model independent

→ combine two complementary techniques: Auger Hybrid detector

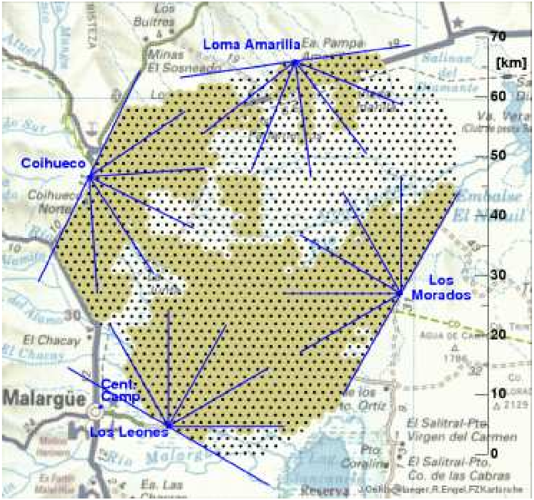
The Pierre Auger Observatory

Two large air shower detectors



16 countries, 63 institutions, $\sim$ 370 collaborators

The Pierre Auger Observatory - Auger South



- area: 3000 km^2
- 4 (3) fluorescence telescopes
- 1600 (1069) water Cherenkov detectors

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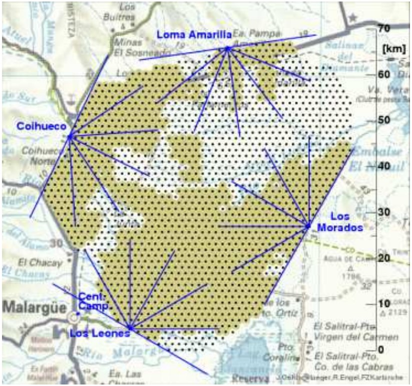

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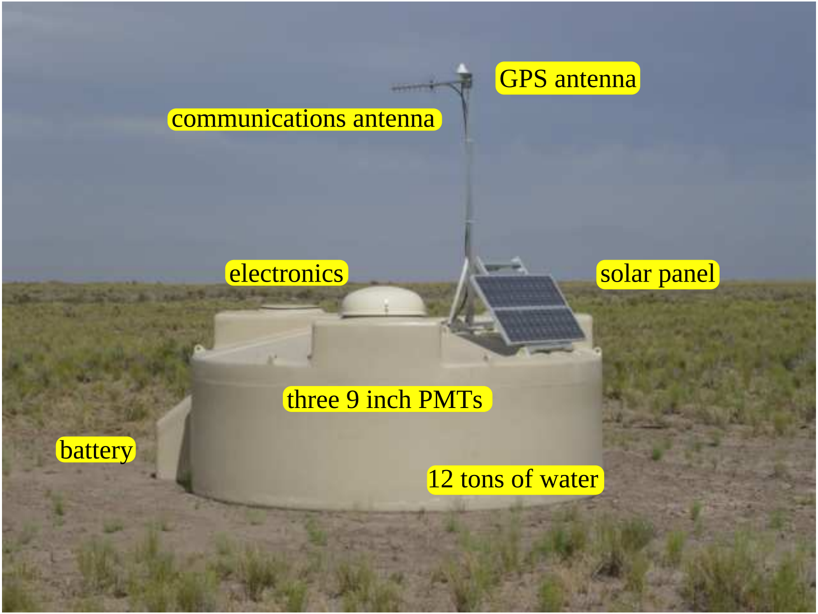
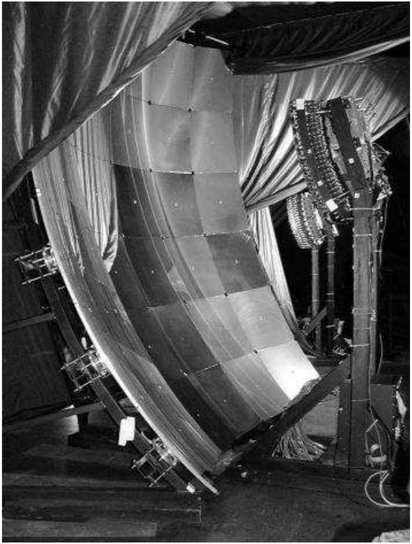
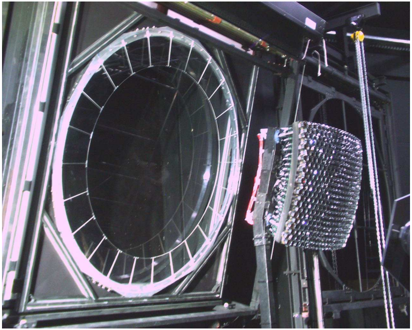
Surface Detector



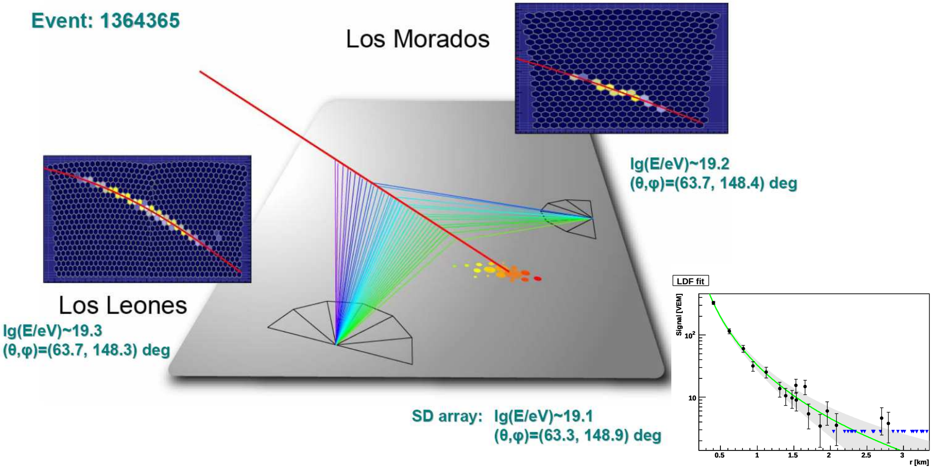
The Fluorescence Detector





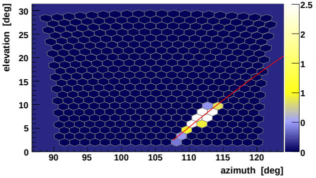
- six mirrors per building
- each $30^\circ \times 30^\circ$ field of view
- 440 pixel PMT camera
- UV filter

Stereo Hybrid event - lg(E/eV)$\sim$19.2, $\theta \sim 64^\circ$

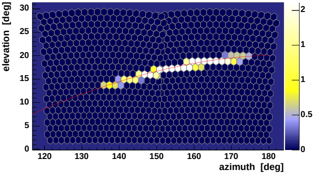


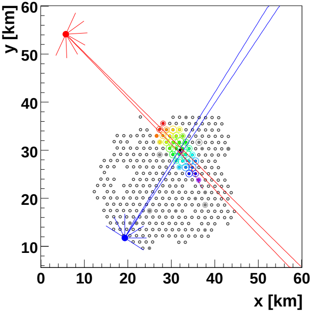
Stereo Hybrid event - lg(E/eV)$\sim$19.7, $\theta \sim 72^\circ$

Coihueco

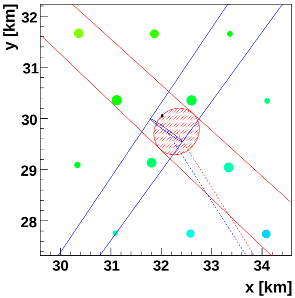


Los Leones





surface detector



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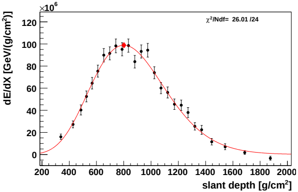

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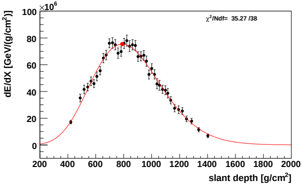
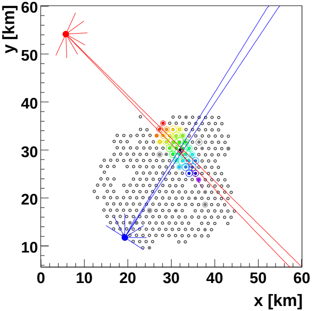
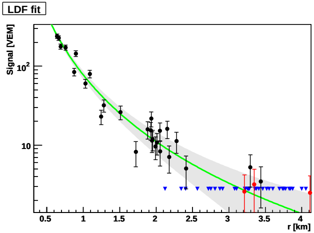


energy estimator:

$$E \propto \int \mathrm{d}E/\mathrm{d}X(X)\,\mathrm{d}X$$



surface detector



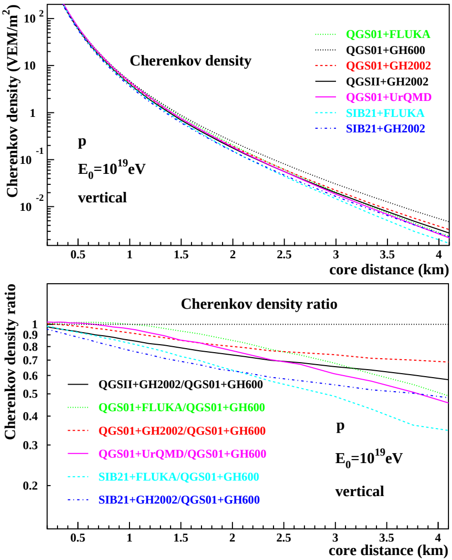
energy estimator:
signal at 1 km:

$$E \propto S(1000)$$

The first Auger data set

- Collection period: January 2004 - June 2005
- zenith angles 0-60°
- Total acceptance:
  - $\sim$ 1750 km^2 sr yr
  - $\approx$ 1 $\times$ AGASA
  - $\approx$ 0.4 $\times$ HiResI
  - $\approx$ 0.7 $\times$ HiResII
- events after cuts:
  - surface detector: $1.8 \cdot 10^5$
  - fluorescence detector: $1.8 \cdot 10^4$

Energy Spectrum - Shower Size to Energy Conversion



(D. Heck, FZK)

Energy calibration with shower simulation?

- → hadronic interaction models
- → extrapolation of accelerator data
- → systematic uncert. hard to assess

New Auger method: cross calibration:

fluorescence detector

↓

surface detector

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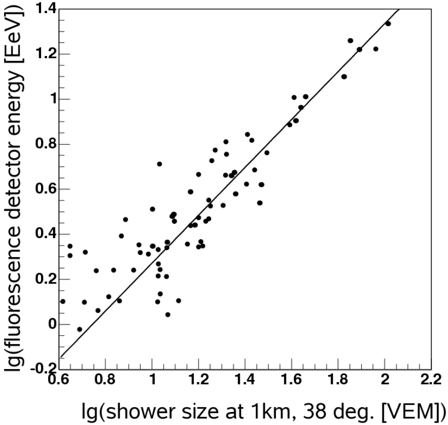

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$\boxed{\text{fluorescence detector}}$

$\downarrow$

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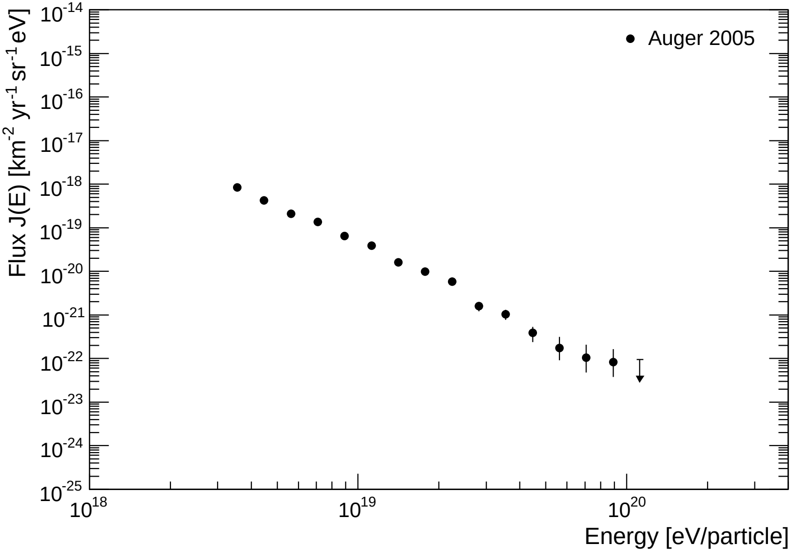
Energy Spectrum - Results



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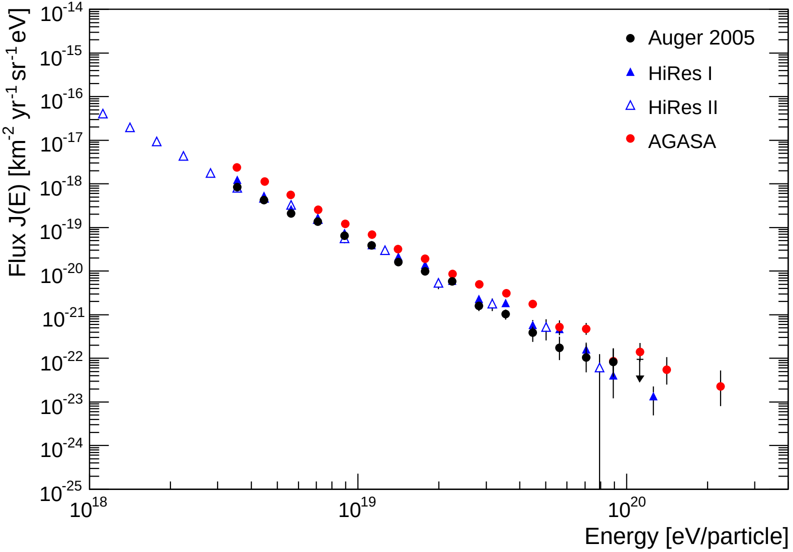

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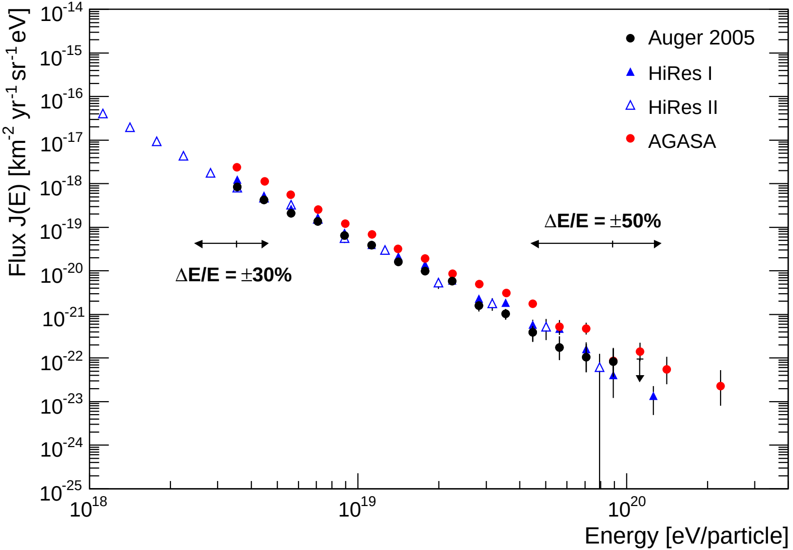
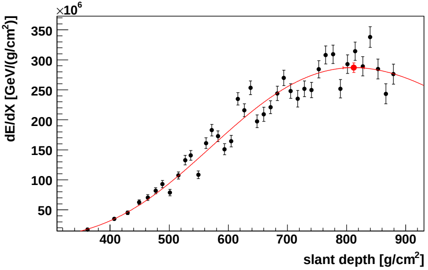
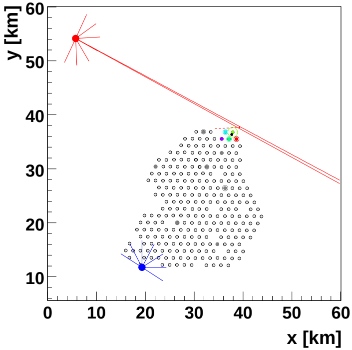


$\Delta E/E$: <u>*currently*</u> dominated by fluorescence yield uncertainty (15%), fluorescence detector calibration (12%) and event statistics

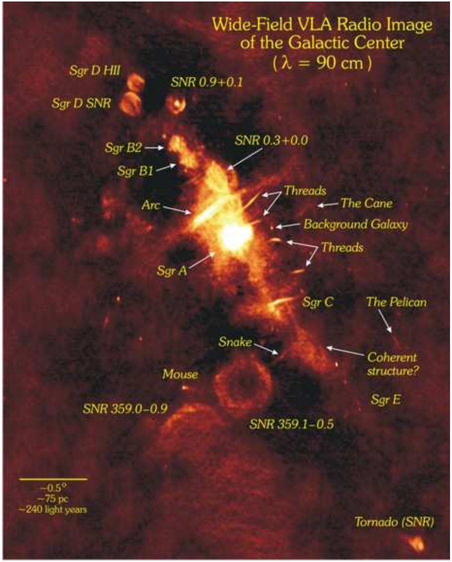
The first event above 10^{20} eV





- $E \sim 2 \cdot 10^{20}$ eV
- lower limit $E > 1.4 \cdot 10^{20}$ eV
- excellent quality in fluorescence detector
- but outside fiducial area of surface detector

The Galactic Center

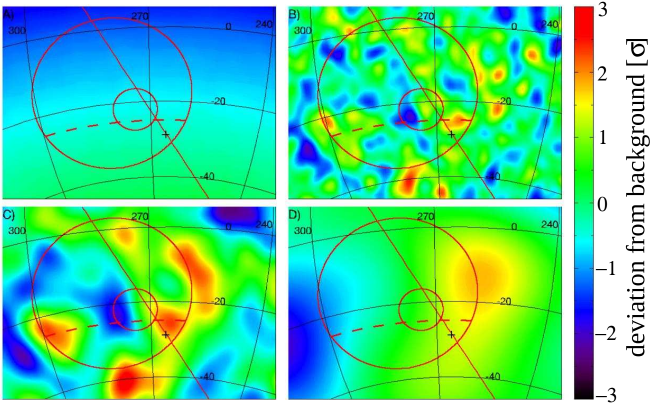


- accelerator of CR?
- black hole $2.6{\cdot}10^6 M_\odot$
- SNR Sgr A East
- TeV gamma rays (HESS)
- neutrons with few 10^{18} eV can reach earth
- signal claimed by AGASA and SUGAR

The Galactic Center in the EeV energy range

AUGER coverage

AUGER resolution:
no excess!



SUGAR excess region:
see 144 events
expect 150.9

AGASA excess region
see 1155 events
expect 1160.7

Photon flux above 10^{19} eV

Experimental signature:

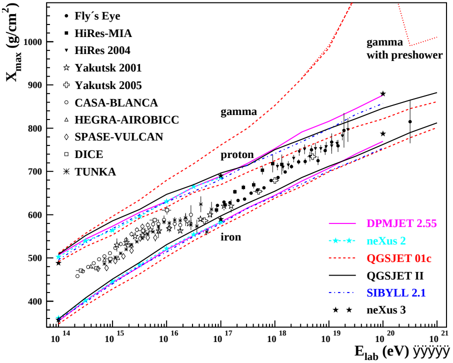
- deeply penetrating showers
- muon poor showers

Analysis:

- selection of high quality FD events, $E>10^{19}$ (16 events)
- χ^2 comparison to photons simulation

Result:

- events compatible with hadronic showers
- $\rightarrow$upper limit



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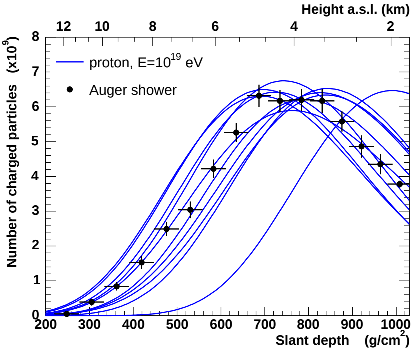

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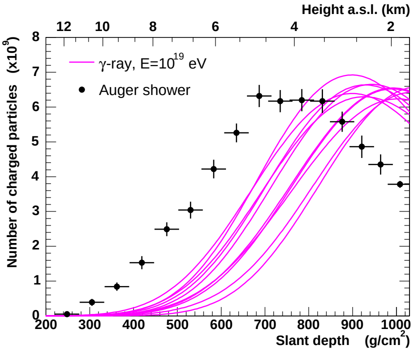

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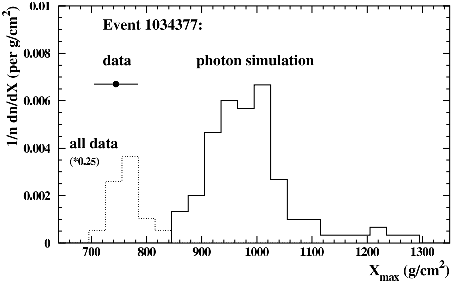

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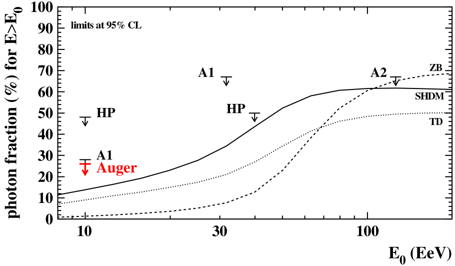

(previous data A1/2: AGASA, HP: Haverah Park and top-down model predictions ZB/SHDM/TD)

Summary and Outlook

- First results from Auger
- Detector still under construction!
- Completion beginning 2007
- Expect factor 7 increased statistics at ICRC07
- Significantly decrease systematic uncertainties
- Rich physics program:
  - Energy spectrum
  - Mass composition
  - Particle astronomy
  - Particle physics
  - UHECR neutrinos
  - ...

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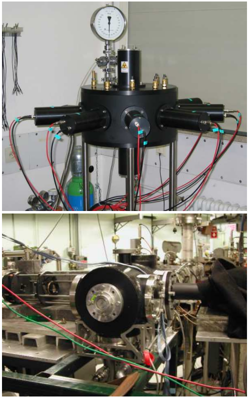
Lab. measurements of fluorescence yield



AIRFLY(ANL), AIRLIGHT(FZK), MACFLY(CERN), etc.

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