HE1.1~HE1.5
EAS, Knee and UHECRs

M.Teshima
Max-Planck-Institute for Physics
<table>
<thead>
<tr>
<th>HE1.1</th>
<th>24 papers</th>
<th>EAS, Knee region</th>
</tr>
</thead>
<tbody>
<tr>
<td>HE1.2</td>
<td>26 papers</td>
<td>EAS, above knee</td>
</tr>
<tr>
<td>HE1.3</td>
<td>28 papers</td>
<td>EAS, UHECR</td>
</tr>
<tr>
<td>HE1.4</td>
<td>78 papers</td>
<td>UHECR</td>
</tr>
<tr>
<td>HE1.5</td>
<td>91 papers</td>
<td>New experiments</td>
</tr>
<tr>
<td>HE1.6</td>
<td>20 papers</td>
<td>M.C. ➔ Dr. Engel</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HE1 total</th>
<th>247 papers</th>
<th>915 pages</th>
</tr>
</thead>
</table>
Statistics

- HE1.1  24 papers EAS, Knee region
- HE1.2  26 papers EAS, above knee
- HE1.3  28 papers EAS, UHECR
- HE1.4  78 papers UHECR
- HE1.5  91 papers New experiments
- HE1.6  20 papers M.C. ➔ Dr. Engel

- HE1 total 247 papers 915 pages

- 14.5 sec/paper ➔ impossible to review all papers
- Will pick up highlights with my biased view; Apologies!!
UHECRs
Energy Spectrum
HiRes Spectrum
Broken power law fits

- Expect 46.2, observe 14
  - $P=7 \times 10^{-7} \ (4.8\sigma)$
Systematic Error in HiRes Mono Energy Spectrum

Energy Scale Uncertainties

- Missing Energy: 5%
- Energy Loss Rate: 10%
- Fluorescence Yield: 6%
- Atmospheric Conditions: 4%
- Photometric Calibration: 10%

Total Energy Scale Uncertainty: 17%

- Flux Uncertainty (with $\gamma=2.8$): 30%
HiRes Stereo
Energy Spectrum

![Graphs showing energy spectrum with different aperture sizes and vaod values.](image-url)
HiRes Stereo
Energy Spectrum

- With geometrical constraint
- Consistent with Mono spectrum
- 11 observed, where 37.4 / 29.8 expectation
- -4.3 $\sigma$, -3.4 $\sigma$ deviation
Auger

HYBRID DETECTOR
Auger

1438 deployed
1400 filled
1364 taking data

090707 ~ 85%

All 4 fluorescence buildings complete, each with 6 telescopes

1st 4-fold on 20 May 2007

AIM: 1600 tanks
Auger: Energy Calibration

Selection of high quality hybrid data without introducing biases
(talk on elongation rate by M. Unger [Auger Collaboration])

⇒ 387 events

⇒ Correlation of $S_{38^\circ}$ and $E_{FD}$

Energy resolution

\[
\frac{\sigma_E}{E} = \frac{\sigma_{E_{SD}}(\sigma_{S38^\circ})}{E_{SD}} \otimes \frac{\sigma_{E_{FD}}}{E_{FD}} = 18\%
\]

16% 8%
Auger SD Energy Spectrum

Cross-checks:
- Different reconst. methods
- $\cos^2\theta$
- Different portions of the array
- Different time periods
- Temperature

All compatible within uncert. (few %)

$5165 \text{ km}^2\text{sr yr}$

$E[\text{eV}]$

$\lg(J/(m^2\text{sr s eV}^{-1}))$

$18.4 \leq \lg(E/\text{eV}) \leq 20.4$

$\times 10^{18} \leq E \leq 2 \times 10^{20}$
Auger SD Inclined Energy Spectrum

Inclined events energy spectrum

Exposure 1510 km² yr sr (29% of θ<60°)

θ < 60°
θ > 60°
Auger Hybrid Concept

The Auger Observatory combines independent measurement techniques

Surface Detector Array (SD)

Air Fluorescence Detectors (FD)

- reliable geometry and energy measurement
- mass composition studies in a complementary way

Event id: 2276329

Hybrid data set used for this analysis:

fluorescence events in coincidence with a least one SD station
Auger Hybrid Energy Spectrum
Energy distribution of events in three observation modes

Energy scale is measured with Hybrid Observation
Auger Three Spectra

Good agreement between the three spectra

- ▼ SD vertical
- △ SD inclined
- ○ Hybrid

\[ \log(Jx E^3 [m^{-2} s^{-1} eV^2]) \]

\[ \log(E [eV]) \]
Auger combined spectrum

Three spectra combined weighting statistical error in each energy bin.

Low energy from Hybrid observation, High energy from SD.

‘ankle’ and ‘steepening’ seen in (nearly) model and mass-independent measurement.
Auger Residual plot

\[ \frac{J}{(AxE^{-2.6})} - 1 \]

\[ \gamma = -3.30 \pm 0.06 \]

\[ E_{\text{ankle}} \approx 10^{18.65} \text{ eV} \]

\[ \gamma \approx -2.62 \pm 0.03 \]

\[ E_{\text{steepen}} \approx 10^{19.55} \text{ eV} \]

\[ \gamma \approx -4.1 \pm 0.4 \]

6 sigma deficit from power-low assumption
HiRes vs. Auger

- Auger 2007
- this work

Uncertainty in Energy scale is achieved to be **22%** and still being reduced.

A significant difference from HiRes spectrum at below 10 EeV.

Slope at Highest End

Auger $y = -4.1 \pm 0.4$

HiRes $y = -5.1 \pm 0.7$
Auger Spectrum
comparisons with Proton Model and
with Mixed composition model

Comparison with Pure Proton Model

Are the data consistent with e+e- dip model?
Need very strong source evolution!

- Strong Source Evolution \((1+z)^5\)
  \(-\gamma_{source} = 2.3\)
- Uniform Source
  \(-\gamma_{source} = 2.55\)

(→ Invited talk by Venya Berezinsky)

Nucleus Model

CR abundance is same as low energy Galactic components

Measuring mass is crucial!

- \(\gamma_{source} = -2.2\)
  Exponential cutoff at
  \(E_{max}^{source} = 10^{21} \times z\)
- \(E_{max}^{source} = 10^{20} \times z\)

Pair creation DIP
invited talk by
V. Berezinsky
Dip
V. Berezinsky

![Graph showing data points for different experiments (Akeno - AGASA, Yakutsk, HiRes I - HiRes II) with energy (E) in eV on the x-axis and J(E)/E^3 in m^2 s^-1 sr^-1 eV^-2 on the y-axis.](image-url)
Dip
V. Berezinsky

Graphs showing data plots for different experiments (Akeno, Yakutsk, HiRes, AGASA) with energy (E) on the x-axis and integrated intensity (J(E)/E^3) on the y-axis.
Pair Creation Dip
V.Berezinsky

![Graphs showing electron energy vs. energy]
Auger Spectrum x 1.5
+M.Teshima
Auger Spectrum x 1.5
+ M. Teshima
UHECRs
photon limit
Auger: Photon limit

Rise time in shower front
Curvature of shower front

Auger 20 years operation will reach to GZK gamma flux of \( \sim 0.1\% \)
Auger Sensitivity to GZK photons
M. Risse and P. Homola

After 20 years, we may see GZK photons with Auger.
UHECRs
Chemical composition, Xmax
HiRes
Xmax distribution
HiRes Xmax
Auger Xmax distribution

Results

\[ \langle X_{max} \rangle = 54 \pm 2 \text{ g/cm}^2/\text{decade} \]

\[ \chi^2/\text{Ndf} = 24/13, \quad P < 3\% \]

Results

\[ \langle X_{max} \rangle = 40 \pm 4 \text{ g/cm}^2/\text{decade} \]

\[ \langle X_{max} \rangle = 71 \pm 5 \text{ g/cm}^2/\text{decade} \]

\[ \chi^2/\text{Ndf} = 9/11, \quad P = 63\% \]
Red: Proton
Blue: Iron

Single line fit gives a better agreement with M.C..

Mixed composition?
Bias in Low energy range?

Energy scale is measured with Hybrid Observation
Red: Proton
Blue: Iron

Single line fit gives a better agreement with M.C..

Mixed composition?
Bias in Low energy range?

54±2 g/cm²
Auger: Chemical composition Preliminary?

**Summary:**

- excellent $X_{\text{max}}$ resolution ($\approx 20 \text{ g/cm}^2$ at high energies)
- $X_{\text{max}}$ scale uncertainty $\leq 15 \text{ g/cm}^2$
- significantly different $D_{10}$ above and below $10^{18.35} \text{ eV}$
- shower simulations $\rightarrow$ mixed composition at all energies
Xmax Auger and HiRes
UHECRs
Anisotropy
Integrate over 20° circles

- Data
- Significance plot for $10^{17.5} < E < 10^{18.5}$ eV.
- Akeno/AGASA result
Auger: Galactic Center

1 < E < 10 EeV - Search for point-like/extended sources

<table>
<thead>
<tr>
<th>search</th>
<th>window size</th>
<th>$n_{obs}/n_{exp}$</th>
<th>$n_s^{95}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>extended</td>
<td>10° (TH)</td>
<td>1463/1365 = 1.07 ± 0.04 (stat) ± 0.01 (syst)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20° (TH)</td>
<td>5559/5407 = 1.03 ± 0.02 (stat) ± 0.01 (syst)</td>
<td></td>
</tr>
<tr>
<td>point-like</td>
<td>0.8° (G)</td>
<td>16.9/17.0 = 0.95 ± 0.17 (stat) ± 0.01 (syst)</td>
<td>5.6</td>
</tr>
</tbody>
</table>
Auger: Harmonic Analysis
Upper limits
UHECRs
Clusters
Auger: Small & Medium scale anisotropy study

AUTOCORRELATION SCAN: AUGER RESULTS

CORRELATION EXCESS AT INTERMEDIATE ANGLES AND LARGE ENERGIES

MINIMUM: $\theta = 7^\circ$, $E > 57.5$ EeV ($N = 19$), $\text{obs/exp} = 8/1$, $P_{\text{min}} = 10^{-4}$

CHANCE PROBABILITY: $P = 2\%$
Auger: Hint of clustering?
6~25 degrees scale

TEST OF SIGNALS FROM PREVIOUS EXPERIMENTS

SMALL SCALE CLUSTERING: $\theta = 2.5^\circ$ and $E > 40$ EeV
AGASA: obs/exp = 7/1.45 (for N=57)
AUGER: obs/exp = 2/1.5
COMPATIBLE WITH ISOTROPIC FLUX

Does a signal appear at a smaller energy?
(possible energy calibration mismatch)

For N = 150 events ($E > 30$ EeV) obs/exp = 14/8.5
No strong excess in the relevant range

INTERMEDIATE SCALE CLUSTERING:
$\theta = 25^\circ$ and $E > 40$ EeV

SOME HINT OF CLUSTERING IS PRESENT, ALTHOUGH WEAKER THAN AT HIGHER ENERGIES
Medium scale anisotropy
M. Kachelriess and D. Semikoz

Looking for structures in UHECRs

✔ World dataset of O(100) public available UHECRs, above the "rescaled" energy of $4 \times 10^{19}$ eV (Hires Scale)

✔ The rescaling is done a priori, to match the ankle feature in the spectrum

"Both the energy dependence of the signal and its angular scale might be interpreted as first signatures of the large-scale structure of UHECR sources and of intervening magnetic fields"

Can we test that?

M. Kachelrieß & D. Semikoz
Auger: Correlation with BL-Lacs
No correlation

**TEST OF PREVIOUS CORRELATION SIGNALS**

**Test A:** 22 BL Lacs  \( m < 18 \)  \( z > 0.1 \) or unknown  \( F_6 > 0.17 \) Jy  (9th catalog)  
(8 in f.o.v.)

**Test B:** 157 BL Lacs  \( m < 18 \)  (10th catalog)  
(76 in f.o.v.)

**Test C:** 14 BL Lacs selected by possible association with EGRET sources  
(3 in f.o.v.)

**Test D:** 204 BL Lacs  \( m < 18 \)  (10th catalog)  
Subclasses: a) 157 BL  (76 in f.o.v.)  b) 47 HP  (30 in f.o.v.)

<table>
<thead>
<tr>
<th>Test</th>
<th>( E_{th} ) (EeV)</th>
<th>Number of events</th>
<th>Angular size</th>
<th>Observed</th>
<th>Expected (isotropic)</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>24</td>
<td>267</td>
<td>2.5(^{\circ})</td>
<td>1</td>
<td>1.0</td>
<td>0.63</td>
</tr>
<tr>
<td>B</td>
<td>40</td>
<td>62</td>
<td>2.5(^{\circ})</td>
<td>2</td>
<td>2.5</td>
<td>0.71</td>
</tr>
<tr>
<td>C</td>
<td>24</td>
<td>267</td>
<td>2.9(^{\circ})</td>
<td>1</td>
<td>0.5</td>
<td>0.41</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a)</td>
<td>10</td>
<td>1672</td>
<td>0.9(^{\circ})</td>
<td>11</td>
<td>12.1</td>
<td>0.66</td>
</tr>
<tr>
<td>b)</td>
<td></td>
<td></td>
<td></td>
<td>8</td>
<td>8.9</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>3.2</td>
<td>0.62</td>
</tr>
</tbody>
</table>

**OUR DATA DOES NOT SUPPORT ANY OF THESE PREVIOUSLY REPORTED EXCESSES OF CORRELATION**
UHECR Theories
Medium Scale Anisotropy
M.Kachelriess & D.Semikoz

>4x10^{19} \text{eV after Global Energy Scaling}

After including penalty $\rightarrow P_{ch} \sim 3 \times 10^{-3}$

Arrival directions for $E>40$ EeV in HiRes ($E>52$ EeV in AGASA)

Probability of autocorrelation

M.Kachelriess and D.S., astro-ph/0512498
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Can we test that?

M. Kachelrieß & D. Semikoz
UHECR possible LLS
A. Olinto et al.

GZK attenuation:
• larger CR density contrasts
• constrasts on larger scales
Continuous source distribution: large scale patterns

From previous sky maps

- Spectra obtained without drawing events ("infinite statistics")
- Dipole \( D \sim \sqrt{(C_1 / C_0)} \) increases with energy
UHECRs from cluster accretion shocks?

**particle confinement**

\[ \text{E} \leq \text{Ze B R} \]

- R~Mpc B~µG
- 10^{20} \text{ eV roughly OK}

**energy budget**

(massive clusters \( \sim 10^{15} \text{ M}_\odot \))

- \( L_{\text{cluster}} \sim 10^{46} \text{ erg/s} \)
- \( n_{\text{cluster}} \sim 10^{-6} \text{ Mpc}^{-3} \)
- \( P_{\text{cluster}} \sim 10^{40} \text{ erg s}^{-1} \text{Mpc}^{-3} \)

UHECR (\( > 10^{19} \text{ eV} \))

- \( u_{\text{CR}} \sim 3 \times 10^{-19} \text{ erg cm}^{-3} \)
- \( \tau_{\text{GZK}} \sim 4(10) \text{ Gyr for p (Fe)} \)
- \( P_{\text{CR}} \sim 10^{37} \text{ erg s}^{-1} \text{Mpc}^{-3} \) (no EGMF)

---

Diagram showing graph with data points and labels.
UHECR spectrum and X+Gamma ray emission

results: spectra & composition

spectra
- consistent with latest HiRes, Auger (AGASA) with “GZK” cutoff
- low $f_{CR}$ generally sufficient inefficient escape?

composition
- consistent with previous HiRes light dominant $<10^{19}$ eV
- prediction: heavy dominant $>10^{19}$ eV

UHE proton-induced hard X+$\gamma$ emission from clusters
$p(10^{19}eV) + \gamma_{CMB} \rightarrow p + e^+e^- (10^{16}eV)$
$e^+e^- + B (-\mu G) \rightarrow keV, e^+e^- + \gamma_{CMB} \rightarrow TeV$
From Knee to Ankle
Tibet AS-$\gamma$ energy spectrum

<table>
<thead>
<tr>
<th>Model</th>
<th>Index of spectrum</th>
<th>Energy range (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QGSJET+ HD</td>
<td>$-2.69 \pm 0.01$</td>
<td>$&lt; 10^{15}$</td>
</tr>
<tr>
<td></td>
<td>$-3.13 \pm 0.01$</td>
<td>$&gt; 4 \times 10^{15}$</td>
</tr>
<tr>
<td>QGSJET+ PD</td>
<td>$-2.64 \pm 0.01$</td>
<td>$&lt; 10^{15}$</td>
</tr>
<tr>
<td></td>
<td>$-3.12 \pm 0.01$</td>
<td>$&gt; 4 \times 10^{15}$</td>
</tr>
<tr>
<td>SIBYLL+ HD</td>
<td>$-2.68 \pm 0.01$</td>
<td>$&lt; 10^{15}$</td>
</tr>
<tr>
<td></td>
<td>$-3.12 \pm 0.01$</td>
<td>$&gt; 4 \times 10^{15}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model</th>
<th>Knee position (PeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QGS+HD</td>
<td>$4.0 \pm 0.1$</td>
</tr>
<tr>
<td>QGS+PD</td>
<td>$3.3 \pm 0.1$</td>
</tr>
<tr>
<td>SIBY+HD</td>
<td>$3.7 \pm 0.1$</td>
</tr>
</tbody>
</table>
NEVOD-DECOR

Coordinate-tracking detector DECOR (~115 m²)

Cherenkov detector NEVOD (2000 m³)

Side SM: 8.4 m² each
- $\sigma_x \sim 1$ cm; $\sigma_\psi \sim 1^\circ$
KASCADE Unfolding: Summary

- knee visible in data structure
- knee caused by light primaries \(\rightarrow\) composition gets heavier across knee
- positions of knee vary with primary elemental group
- relative abundancies depend strongly on high energy interaction model
- result only weakly dependent on low energy interaction model
- result consistent for different data sets
- no (interaction) model can describe the data consistently
- all-particle spectra agree inside uncertainties (EPOS a bit lower)
Muon Production Height $H_{\mu A}$ versus $\lg N_e/\lg N_\mu$

The muon production height $H_{\mu A}$ can be calculated for each muon track in a shower. After correction for elongation rate as function of $\lg N_\mu$ and $\lg N_e$ the resulting $H_{\mu A}$ distribution exhibits regions of distinct $H_{\mu A}$ in a colour code with 40g/cm$^2$ step size.
KASCADE-Grande: the experimental set-up

- Forschungszentrum Karlsruhe, 48.1 N, 8.4 E, 110 m
- Energy range: $10^{16} - 10^{18}$ eV
- Multi-observables (charged particles, muons at different thresholds)
- 2 different arrays overlapping each other

<table>
<thead>
<tr>
<th>Detector</th>
<th>Detected EAS component</th>
<th>Sensitive area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grande</td>
<td>Charged particles</td>
<td>37x10</td>
</tr>
<tr>
<td>Piccolo</td>
<td>Charged particles</td>
<td>8x10</td>
</tr>
<tr>
<td>KASCADE array e/γ</td>
<td>Electrons, γ</td>
<td>490</td>
</tr>
<tr>
<td>KASCADE array μ</td>
<td>Muons (Eμ=230 MeV)</td>
<td>622</td>
</tr>
<tr>
<td>MTD</td>
<td>Muons (Tracking) (Eμ=800 MeV)</td>
<td>3x128</td>
</tr>
<tr>
<td>MWPCs/LSTs</td>
<td>Muons (Eμ=2.4 GeV)</td>
<td>3x129</td>
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<tr>
<td>LOPES 30</td>
<td>Radio</td>
<td></td>
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<tr>
<td>Trigger Plane</td>
<td>Muons (Eμ=490 MeV)</td>
<td>208</td>
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<tr>
<td>Calorimeter</td>
<td>Hadrons</td>
<td>9x304</td>
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</tbody>
</table>
KASCADE-GRANDE
Size spectrum

Shower size spectrum

- vertical events
- 290 days of data taking
- fiducial area 0.3 km$^2$
- flux multiplied by $N_{ch}^3$

...not deconvoluted for reconstruction uncertainties!

...low statistics to see spectral features!

ICRC 2007
F. Di Pierro et al. KASCADE-Grande Coll.
4) Confronting MC and KG data

Differences between MC and KG data increase with $\theta$.

- Shower simulations:
  More muons/harder secondary $\mu$ spectrum in MC are needed?

- Detector simulation?

For $50^\circ \leq \theta \leq 70^\circ$:
$\Delta \Phi_\mu \sim 20\%$

Muon spectra from inclined showers – J.C. Arteaga

ICRC 2007, Merida, Yucatan, Mexico
KASCADE-GRANDE
Chemical composition

CORISKA QGS-JET II
KASCADE-GRANDE

No point sources
KASCADE-GRANDE
Upper limit for Large scale anisotropy

Rayleigh amplitude

log_{10} (E_0 [eV])

- Agasa
- Akeno
- Buckland Park (1983)
- Buckland Park (1989)
- EAS-TOP
- Haverah Park
- Kamiokande
- Yakutsk

KASCADE 95%
Grande, Rayleigh 95%
Grande, East-West 95%
preliminary
KASCADE-GRANDE
New Energy Estimator S(500)
New Projects
Towards Bright Future
New commissioning Projects, New Projects and R&D

- TA is in commissioning phase
  - Full operation from autumn 2007
  - TALE will follow to extend coverage toward lower energies (Transition from galactic to extragalactic)

- ARGO-YBJ
  - In full operation
  - Moon shadow, Crab, Mrk421 detection

- Auger North (200,000 km² sr yr at 2014)

- From Space
  - TUS, JEM-EUSO, Super-EUSO
  - ~M km² sr yr(L)

- R&D for radio detection \(\Rightarrow\) H. Falcke’s talk
  - LOPES, CODALEMA
  - Looks very promising

- New photodetector
  - SiPM \(\Rightarrow\) Improve HEAP experiments

- Air Florescence yield measurements
  - Flash, Airfly
  - Final results will come soon
TA Scintillators and Florescence detectors
A shower event recorded by TA-SD

Trigger > 3MIPs

Very preliminary

Log(E[eV]) = 19.1
Zenith = 36.3[deg]
Azimuth = 241.2[deg]
Example: shower event

June 20, 08:18:21 (UTC), trigger ID 0000169

Camera08

Camera09

July 7, 2007

ICRC20007, Merida, Mexico
Telescope Array

- Balanced SD ~ FD hybrid for UHECRs
- Aperture = AGASA x (12 ~ 23)
- Complimentary to Auger South
- Energy spectrum: by SD and FD independently
  - both are from EM component measurements
- GZK cutoff, Cluster in North?
- Construction ~95% completed, commissioning phase
- Autumn 2007, Full Data Collection starts.
- Low Energy extension TALE planned.
TALE $10^{16.5}$eV~$10^{18.5}$eV

**TALE Infill Array**

- **Standard TA**: 1.2 km grid
- **Surface Infill**: ~100 detectors on 0.4 km grid
- **Muon stations**: 16 on 0.2 km grid, additional detectors on larger grid

**Galactic/Extragalactic Transition:**
HiRes/MIA hybrid experiment, and HiRes Stereo, results show transition from heavier to lighter composition, complete by about $10^{18}$ eV.
TALE Florescence detector and Muon detector

Tower Fluorescence Detector:

3 additional rings of mirrors, 31° – 72°
Each mirror 3x HiRes mirror area
(See D. Bergman poster)

Left: TALE-1 site, showing 3rd 4th and 5th rings
Right: Prototype 4th ring detector

TALE \( \mu \) Prototype
- “Sand Box” muon detectors
- Shield 25 m² scintillator from EAS electromagnetics

See also J. Belz poster
The Pierre Auger Observatory – 2 Sites

Need for 2 sites realized since beginning of project

Northern Site: Colorado
- Retain features & functionality of Southern Site
- Hybrid detection & energy calibration
- Water Cherenkov surface array
  - 4000 stations, 10,370 km²
  - Square mile grid

Southern Site: Mendoza
- Hybrid detection & energy calibration
- Water Cherenkov surface array
  - 1600 stations, 3000 km²
  - 1.5 km triangular grid
- Completion end 2007
- Science flowing – 38 papers here

Altitude and latitude are similar

Southern and Northern sites are shown at the same scale
Auger North

FD Layout

- FD layout optimized to provide maximum hybrid coverage per telescope
- 18 30° field of view telescopes organized in 3 eyes
- Telescope design similar to Auger South design, incorporating HEAT (paper #65) enhancement updates (new electronics, cost optimized enclosure)

Surface Array

- Tank with internal rotationally molded polyethylene foam insulation
  - Northern site is colder
  - Central hatch for single large PMT
  - Cost reduction refinement
  - 2nd hatch for assembly access

Dots indicate positions of 4032 tanks
Auger North

Exposure

- It is time to design the Northern Site
- Build upon lessons learned in the South

Assumes:
- Auger South finished end of 2007
- Auger North construction starts 2009
- Auger North construction finished 2012

> Auger North cosmic ray aperture is 3.3x Auger South
> Auger North neutrino aperture 2x Auger South
JEM-EUSO Telescope will be attached to Exposure Facility of Japanese Experiment Module (JEM/EF) of ISS in 2013.

Vertical Mode

Tilted Mode
Larger effective area (x5) with ~35° tilt
Progress of the study of EECR expected in the near future:

by Boris Khrenov 2006

JEM-EUSO ~1M km² sr yr, >1000 events above 6x10^{19}eV
If we get >1,000 events,

- 1,000 events: $E > 7 \times 10^{19} \text{eV}$
- Several dozen clusters are expected
- All sky coverage
Summary

Energy Spectrum of UHECRs
- HiRes and Auger saw the steepening of the spectrum above $4 \times 10^{19}$ eV with 5 sigma and 6 sigma
- GZK cutoff?

Chemical Composition of UHECRs
- Auger Xmax suggests mixed composition
- HiRes claimed proton dominance above $10^{18}$ eV

Anisotropies
- No galactic center excess was found with Auger around $10^{18}$ eV
- HiRes: deficit in the direction of anti-galactic center

- Small scale anisotropy was not found with Auger
  - The effect of galactic magnetic field must be considered
- Hint of medium scale anisotropy with Auger
- World data also shows medium scale anisotropy
  - Relating with large scale structure?
Many open questions are popped up

Energy scale problem
- 1.2~1.5 factor difference between Auger and other experiments
- FD energy (FY) ↔ SD energy (MC-Calibration energy)

What is ankle?
- Pair creation dip ➔ V. Berezinsky; Beautiful results
- Transition from galactic to extragalactic

Chemical composition at UHE
- Proton dominance? ➔ support pair creation dip hypothesis
- Mixed composition ➔ photodisintegration energy (Eth ∼ Ag) ➔ small elongation ratio D10 ➔ Support Auger Xmax?

Break in energy spectrum at 4×10^{19}eV
- GZK Cutoff?
- Acceleration limit?
- Drop off of lighter elements?

Medium scale anisotropy
- Relating with large scale structure?
- Deflected images of point sources (North-South asymmetry)
Thanks
Uncertainty of GMF models

Deflection in degrees in galactic magnetic field models for protons with energy $4 \times 10^{19}$ eV

M. Kachelriess et al. astro-ph/0510444

TT model

HMR model

PS model
Global energy rescaling

$E^2F(E)$ vs $E$ [eV cm$^{-2}$ s$^{-1}$ sr$^{-1}$]

- Akeno
- AGASA
- HiRes I
- HiRes II
Global energy rescaling
Anisotropy measurement by LAAS
A.Iyono et al.
ARGO-YBJ: Moon Shadow
-10 sigma in 558hrs, $\Delta \theta = 0.51$ degrees

- The max significance: $\sim 10$ standard deviations, shifted by 0.04 toward the West and 0.14 toward the North with respect to the nominal Moon position.
- The distribution of the observed deficit events projected along the W-E and N-S axes. The Gauss width:
  $\sigma_{E-W} = 0.43 \pm 0.07, \sigma_{N-S} = 0.51 \pm 0.09.$
The TUS detector will be launched on a new platform separated from the main body of the “Foton” satellite (RosCosmos project, Samara enterprise, launching in 2009-2010). Satellite limits for the scientific instrument are: mass 60 kg, electric power 60 Wt, orientation to nadir ±3°.

Preliminary TUS design:

1- in the transportation mode, 2 - in operation.

Mirror area is up to 2 m², pixels cover 4000 km² of the atmosphere (orbit height 400 km).
Sampling of Previous Results: Kakimoto et al., Nagano et al., and T461 (FLASH test run).

Ratio of fit to (Kakimoto, Nagano, and T461) to fit to Kakimoto = 1.00 ± 0.06

FLASH result will be shown at the air fluorescence conference at El Escorial in Sept.
Previous Measurement of the Absolute Fluorescence Yield

- Sampling of Previous Results: Kakimoto \textit{et al}., Nagano \textit{et al}., and T461 (FLASH test run).
- Ratio of fit to (Kakimoto, Nagano, and T461) to fit to Kakimoto = $1.00 \pm 0.06$
- FLASH result will be shown at the air fluorescence conference at El Escorial in Sept.
Auger: Event selection for Energy spectrum study

- Physics trigger:
  3 stations (equilateral \( \Delta \), ToTs)

- Full efficiency:
  \( E \sim 3 \times 10^{18} \text{ eV} \)

- Quality trigger:
  Hottest tank surrounded by 6 active stations

- \([0, 60^\circ]\)

- 1.1.2004 – 28.2.2007

- Exposure: 5165 km\(^2\) sr yr
  (uncertainty 3%)

Aperture:
- # of elementary cells; \( A_c = 1.95 \text{ km}^2 \)

Exposure:
- Integr. of array evolution

![Graph showing trigger probability vs energy with angular distributions at different angles.](image)
Auger SD Energy Spectrum Residual plot

![Graph showing energy spectrum with residual plot](image-url)