Observation of UHECRs in horizontal flux

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for DECOR Collaboration
DECOR Collaboration

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Outline

- Introduction
- Experimental setup
- Experimental runs 2002-2004
- Preliminary results
- Calculations (CORSIKA)
- Conclusions and problems
Flux of Cosmic Rays

1 particle /m² second

EAS detection
19th ESRS, 3 Sep '04, Florence

Flux of Cosmic Rays

- 1 particle/m² second
- Knee ~ $5 \times 10^4$ m²
- EAS detection KASCADE
- Direct measurements
- 1 particle/m² year

Energy (eV)

Flux (m² sr s GeV⁻¹)
19th ESRS, 3 Sep '04, Florence

Flux of Cosmic Rays

1 particle /m² second

Knee

Ankle

~ 5 ⋅ 10⁴ m²

KASCADE

AGASA

Direct measurements

EAS detection

1 particle/ m² year

1 particle/ km² year

0 4km

100 km²
19th ESRS, 3 Sep '04, Florence

**Flux of Cosmic Rays**

- Knee: $1 \text{ particle/m}^2 \text{ second}$
- Ankle: $1 \text{ particle/m}^2 \text{ year}$
- 1 particle/km$^2$ century

**Direct measurements**

**EAS detection**

Pierre Auger Observatory

- 50 km
- 3000 km$^2$
Experimental complex NEVOD

- Length: 9 m
- Width: 9 m
- Height: 26 m
- Volume: 2000 m³
Experimental complex NEVOD

Detection system: spatial lattice of quasispherical optical modules (QSM) – up to 1500 PMTs
Experimental complex NEVOD

Detection system: spatial lattice of quasispherical optical modules (QSM) – up to 1500 PMTs
Coordinate detector DECOR

1992-1999 – Side DECOR
8 SM; 32768 channels;
70 m²
Coordinate detector DECOR

Side DECOR

8 SM; 32/66 channels;
70 m²
Coordinate detector DECOR

1992–1999
8 SMSM; 32768 channels
70 m

1998–2002
TOP DECOR
4 SMSM; 19456 channels;
46 m²
Coordinate detector DECOR

1992–1999

8 SMS; 32768 channels

70 m²

TOP DECOR

1998–2002

4 SMS; 19456 channels

46 m²

46 m²
Coordinate detector DECOR

1992–1999

Side DECOR

8 SMSM; 32768 channels;

70 м²

1998–2002

TOP DECOR

4 SMSM; 19456 channels;

46 м²
Coordinate detector DECOR

- **Side coordinate detector** - horizontal cosmic ray flux investigations (60°-90°). Systematic study of the processes of cosmic ray energy transformation including multiple muon generation in the range of interaction energies – 0.1-1000 PeV

DECOR Surpermodule

- **The basic element** - plastic streamer tube chamber with resistive cathode coating

- **Module** - 16 chambers, arranged in a vertical plane one above another and equipped with two-coordinate external strip readout system (256X+256Y channels with 1.0 and 1.2 cm pitch, respectively)

- **Supermodule (SM)** - 8 such modules arranged vertically side by side
<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of chambers</td>
<td>1664</td>
</tr>
<tr>
<td>Number of readout channels</td>
<td>52224</td>
</tr>
<tr>
<td>Effective area of the supermodule</td>
<td>8.4 m²</td>
</tr>
<tr>
<td>Total effective area</td>
<td>~110 m²</td>
</tr>
<tr>
<td>Coordinate measurement accuracy</td>
<td>~ 1 cm</td>
</tr>
<tr>
<td>Angular resolution of one supermodule</td>
<td>&lt; 1°</td>
</tr>
</tbody>
</table>
DECOR response reconstruction

Nl=57, N5=47, N6=43, NR1=0, NR2=0
NGroup=16

Date=13-01-04 02:17:06.061 Nevent=40526 $\phi=299.0$ $\theta=85.8$ degrees
Main tasks:

- investigation of horizontal cosmic ray flux (spatial and angular distribution of muon groups, albedo muons, and so on);
- development of detection, event reconstruction and classification techniques.

Selection of events

is based on coincidences between signals from separate supermodules, and also with signals formed in external electronics system of Cherenkov detector NEVOD.

<table>
<thead>
<tr>
<th>Period</th>
<th>Live Time</th>
<th>No. events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec 01-July 02</td>
<td>~3700 hours</td>
<td>~1.5×10^8</td>
</tr>
<tr>
<td>Dec 02- June 03</td>
<td>~3410 hours</td>
<td>~1.6×10^8</td>
</tr>
<tr>
<td>Nov 03- June 04</td>
<td>~3955 hours</td>
<td>~1.6×10^8</td>
</tr>
</tbody>
</table>
Experimental data

In total: 10580 hr live time

Muon bundles of low multiplicity

- $N_\mu \geq 2$; $\theta = 55^\circ - 90^\circ$; 6420 hr;

Muon bundles of large multiplicity

Two selections:

- $\geq 60^\circ$; $N_\mu \geq 5$; 630 hr; 2784 events
- $\geq 75^\circ$; $N_\mu \geq 10$; 10580 hr; 208 events
Muon bundles of low multiplicity at large zenith angles ($\theta = 55^\circ-90^\circ$)

Reference track - track crosses 2 SM on two different walls of SIDE DECOR ($91 \times 10^6$ events)

Additional track:
- reconstructed in any SM and parallel to the reference one within $5^\circ$ cone;
- $d > 1$ m;
- additional track must penetrate the detector NEVOD water volume ($E_{th} = 1.5 - 7$ GeV).

In total 9633 selected events
Zenith-angle dependence of ratio of muon bundles to single muons

Ratio of muon bundles to single muons

$N_{\mu,2}/N_{\mu,1}$

$10^{-4}$

$10^{-5}$

60 64 68 72 76 80 84 88

Zenith angle, $\theta^\circ$

DECOR 2004 (experiment)
CORSIKA (GHEISHA2002+QGSJET01)
Near horizontal muon bundles with large multiplicity

DECOR response. Event #847205
Near horizontal muon bundles with large multiplicity

Muon bundle with **132 tracks**. Event #847205. $\theta=79.7^\circ$

Date=05-05-03 06:11:04.043 Nevent=847205 fm=123.1 tm=79.7
$> 60^\circ, N_\mu > 5; 630 \text{ hr}$
\[-2.64 \pm 0.05\]

$> 75^\circ, N_\mu > 10; 10579 \text{ hr}$
\[-2.32 \pm 0.17\]
Monte Carlo simulation of EAS muon component at large zenith angles

- Standard atmosphere
- **CORSIKA** (6.020 and 6.031)
- **QGSJET01** ($E_h \geq 80$ GeV)
- **GHEISHA2002** ($E_h < 80$ GeV)
- 110 m under sea level
- $\theta \geq 70^\circ$ - CURVED option
- Magnetic field – not included
- Primary protons, Fe
- Power low primary spectra and/or fixed energy set
Monte Carlo simulation of EAS muon component at large zenith angles

\[ \theta \geq 70^\circ \]

- CORSIKA 6.031
- \( N_{\mu} \geq 1 \)
- \( \theta = 80 - 88^\circ \)
- \( N_{\mu} \geq 2 \)
Monte Carlo estimation of effective energies responsible for high multiplicity muon bundle generation

- **CORSIKA (6.020) QGSJET01+GHEISHA2002**
- Primary **protons** and Fe
- Zenith angles: **60° and 80°**
- S det = 36 m²
- Multiplicity: \(\geq 5 (\theta=60°)\); \(\geq 10 (\theta = 80°)\)
Monte Carlo estimation of effective energies responsible for high multiplicity muon bundle generation

~20 km

Θ = 80°

~100 km

S_{det} = 36 \text{ m}^2

effective area

(\geq 10 \mu \text{ in detector})
Monte Carlo estimation of effective energies responsible for high multiplicity muon bundle generation
Muon bundles of large multiplicity

CORSIKA 6.020

$\theta = 60^\circ$, $N_{\mu} \geq 5$

$S_{\text{det}} = 36 \text{ m}^2$
Muon bundles of large multiplicity

CORSIKA 6.020
\[ \gamma = 3.1, \theta = 80^\circ \]
\[ S_{\text{det}} = 36 \text{ m}^2 \]
\[ N_{\mu} \geq 10 \]
Conclusions and problems

- First results of measurements of muon bundle distribution in multiplicity (spectra of local muon density) and their angular distribution at zenith angle $\theta > 60^\circ$ are obtained.

- Preliminary data on the angular dependence of the ratio of intensity of muon bundles to that of single muons reveal the flattening of this ratio at zenith angles more than 84 degrees.

- In frame of traditional picture, for detected events the primary particles with energies in the range from $10^{11}$ eV (single muons) and up to more than $10^{17}$ (bundles with $N_\mu \geq 10$ at $\theta > 80^\circ$) are responsible.
Conclusions and problems

- For quantitative analysis of obtained results, extensive simulations of expected muon group characteristics in the wide zenith angle range by means of reliably tested code are necessary.

- Experimental data accumulation and analysis are continued.

- Preliminary analysis of obtained experimental data in horizontal flux demonstrates the ability of such not large detector as NEVOD-DECOR complex to perform cosmic ray studies in a very wide energy range from $10^{11}$ eV to more than $10^{17}$ eV.