UNDERGROUND NEUTRON EVENTS AT TIEN SHAN

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Tien Shan EAS detector complex

Location: Northern Tien Shan, 43° North, 75° East, 3340m a.s.l.

**CENTER-I:**
* EAS detector system;
* neutron and gamma ray detectors;
* underground set;
* radio antennas.

**CENTER-II:**
* EAS detectors;
* ionization-neutron calorimeter (*INCA*).
Underground neutron monitor

Location
Placed at 11m depth of rock absorber (∼2000g/cm², 5 GeV muon threshold)

Internal set-up
1 - neutron counter, 2 - moderator, 3 - lead target, 4 - rubber (outer moderator&shielding), 5 - iron absorber, 6 - plastic scintillators

Signal multiplicity of neutron counters (Geant4 simulation)
Old results & open questions of the 2007–2010 years experiment

- Multiplicity spectra of neutron events

\[ \mathcal{R} = \frac{I_{\text{ON}}}{I_{\text{UNDER}}} \sim 300 - 600 (?) \]

“Upper/Lower” correlations

\[ I(\geq M), \text{ m}^{-2} \cdot \text{s}^{-1} \]

\[ E_h, \text{GeV} \]

\[ M \]

\[ \text{ON-GROUND} \]

\[ \text{UNDERGROUND} (\mu\text{-interact. (?)}) \]
**Geant4 simulation for HADRONIC primaries**

- Hadronic products in the soil (*Geant4* simulated)

- Hadron penetration in soil

**Expected intensity relation**

\[ R = \frac{I_{ON}}{I_{UNDER}} \sim 10^5 \]

(instead of \( \sim 300-600 \))
**Geant4 simulation for MUONIC primaries**

- **Energy spectrum of muons in underground room**
  
  ![Energy Spectrum Diagram](image)

  - Considered **Geant4 muonic processes:**
    - electromagnetic (scattering, ionization, bremsstrahlung, pair production);
    - $\mu$-nuclear; $\mu$-decay; $\mu^-$-capture.

- **Simulation conditions:**
  - $\mu^\pm$ primaries;
  - $\Delta I/\Delta E_\mu \sim E_\mu^{-2.5}$;
  - $I(E_\mu > 200\text{GeV}) = 0.072 \text{m}^{-2}\text{s}^{-1}$;
  - the lower energy limit of 5 GeV.

- **Neutron multiplicity spectra**
  
  ![Neutron Multiplicity Diagram](image)
Long term monitoring data

Dec 2012 ... May 2018

UNDERGROUND MONITOR (UPPER UNIT)

UNDERGROUND MONITOR (LOWER UNIT)

NM64 SUPERMONITOR (ON-GROUND)

ATMOSPHERIC PRESSURE

Date / Time, UT

The underground neutron events and the EAS

- Underground neutron multiplicity spectra

- $M/N_e/R$ correlations

- Relative observation frequency
  "events with underground neutrons / total EAS count"

- Statistics / 1000h
  * $M \geq 100$: 30 events, 1 of them is EAS connected;
  * $M \geq 200$: 6 ev., 0.4 EAS;
  * $M \geq 300$: 0.2 ev., 0.1 EAS.
Delayed underground neutron signal in EAS connected events

- **Normal event**

  24.12.2017 07:00:12 [1052] BCD

- **Delayed underground event**

  06.01.2017 09:40:14 [1845] BCD

$T \simeq 1200 \mu s (!)$
CONCLUSION

- investigation of neutron events at the Tien Shan underground monitor has been performed during continuous ∼10 year long period of time.
- from comparison of experimental and Geant4 simulated neutron multiplicity spectra it follows that the great bulk of the events observed underground can be rather convincingly explained by interaction of cosmic ray muons with internal material of neutron detector.
- in synchronous operation of the underground neutron detector and on-ground shower installation it was found that origination frequency of underground neutron events starts to grow significantly around the knee of primary cosmic ray spectrum.
- some peculiar EAS events were detected when the neutron signal underground reveals itself only ∼100–1000 µs after passage of the front of shower particles.