Local density spectra of electron and muon EAS components in primary energy range from 10^{14} to 10^{18} eV

Unique Scientific Facility Experimental Complex NEVOD

M.B. Amelchakov, A.G. Bogdanov, S.S. Khokhlov, R.P. Kokoulin, A.A. Petrukhin, I.A. Shulzhenko, I.I. Yashin

National Research Nuclear University MEPhI (Moscow Engineering Physics Institute),
115409 Moscow, Russia

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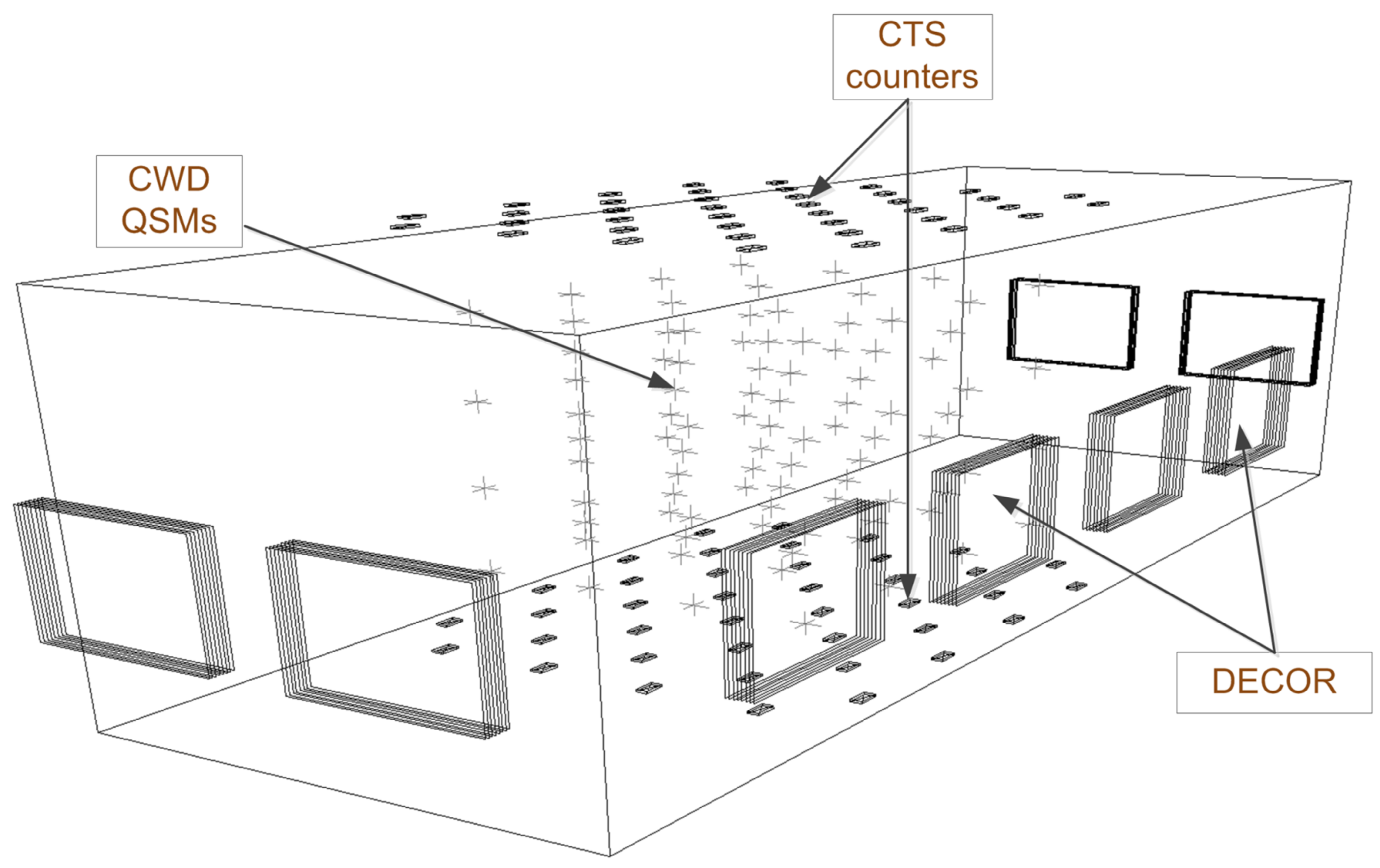
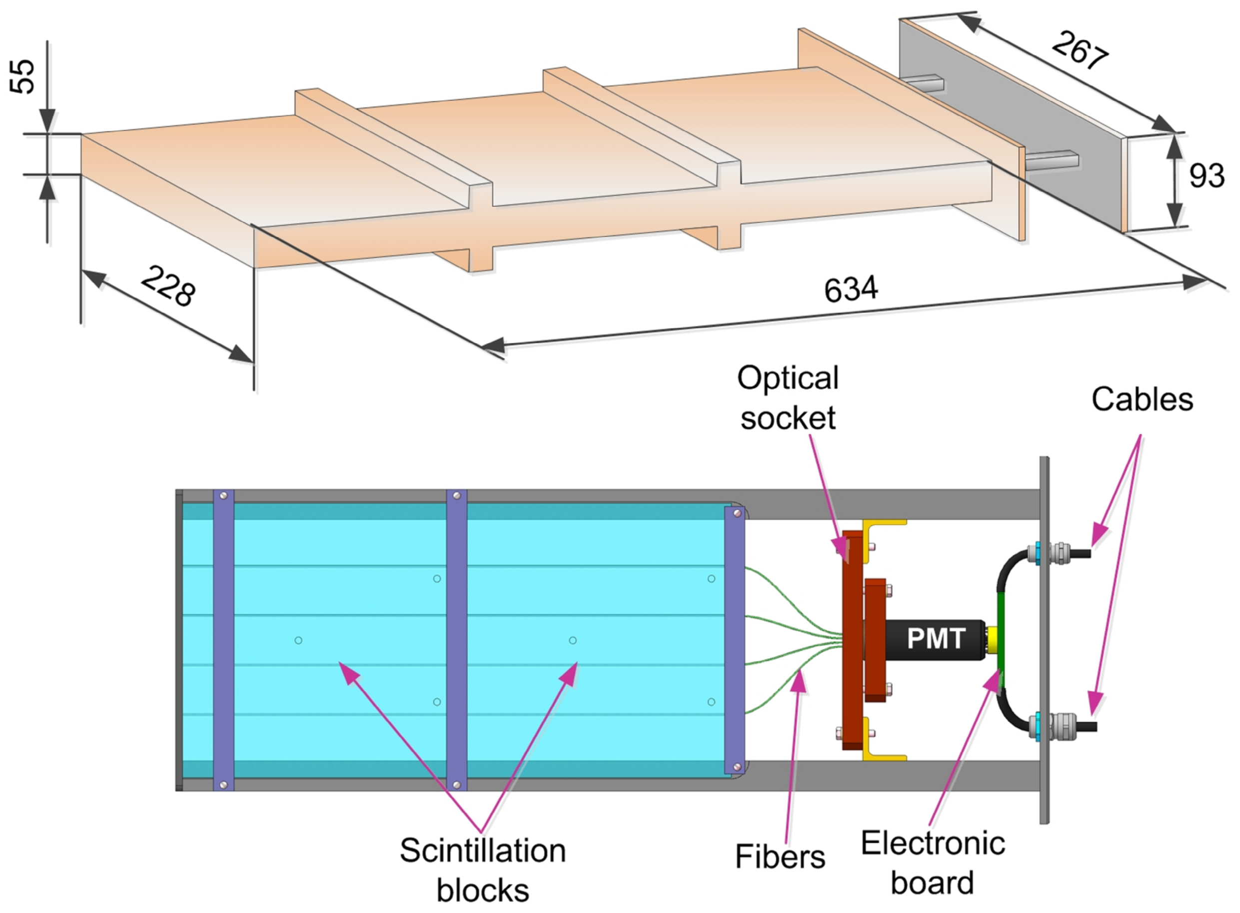
Calibration telescopes system (CTS) of the Experimental complex NEVOD

The calibration telescope system was earlier developed for Cherenkov water detector (CWD) calibrating by the direct Cherenkov light from the tracks of the muons in the Experimental complex NEVOD. CTS consists of two planes of scintillation counters. The distance from the bottom to the top plane is 9.45 m. In each plane, there are 40 scintillation counters arranged in a chess order on the 8×10 m^2 area. Any pair of counters – one in the bottom and one in the top planes – forms a muon telescope. The quasi-spherical modules of CWD are located in the water tank (9×26×9 m^3) between CTS planes. The water fills the tank up to the level of 8.6 m. The eight supermodules of the coordinate-tracking detector DECOR surround the CWD water tank from three sides.



The CTS scintillation counter



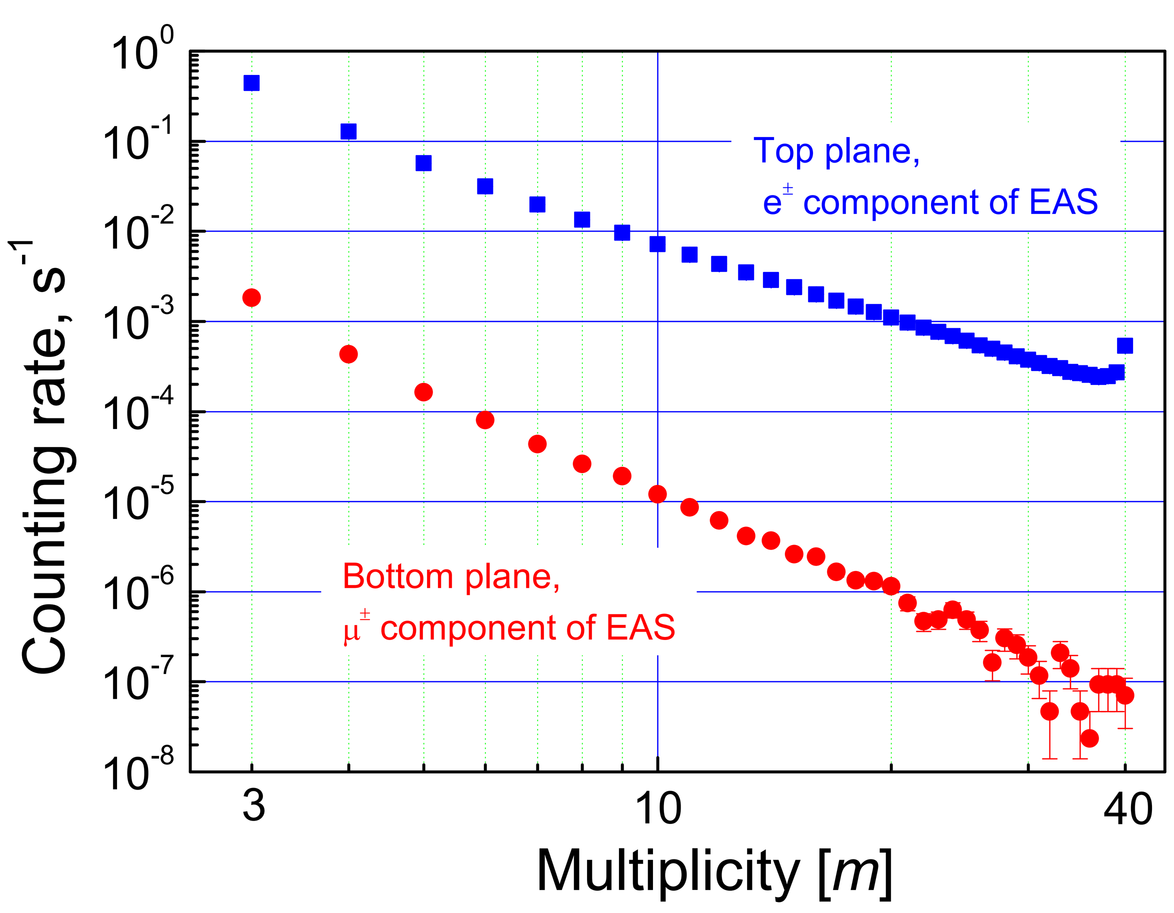
The triggering conditions for CTS events:

1. The coincidence in the top plane of no less than three hit counters is used for registration of EAS electron component.
2. The coincidence in the bottom plane of no less than two hit counters is used for registration of EAS muon component.
3. The coincidence of at least one hit counter in each plane is used for calibrating CWD and CTS counters.

1. Scintillation block size	– 40×20×2 cm^3.
2. Registration efficiency of relativistic particles	– 0.95
3. The light collection non-uniformity	– < 20%
4. Amplitude range	– ~60 m.i.p.

The technique of the local density spectrum reconstruction:

Multiplicity spectra for two planes



We present the technique of spectrum reconstruction based on the multiplicity of hit counters. For calculations we assume that the local density spectra of EAS components have a power form and choose the trial spectrum as:

$$\frac{dF_0}{dD d\Omega} = A_0 (D/D_0)^{-(\beta+1)} f(\theta) \ [\mathrm{m^2 s^{-1} sr^{-1}}] \qquad D_0 = 1 \ \mathrm{m^{-2}}$$

Due to CTS small size, the probability of counter hit is: $p = 1 - \exp(-S_{\mathrm{eff}} D)$

Effective counter area depends on zenith angle θ of EAS arrival, and registration efficiency η: $S_{\mathrm{eff}} = \eta S \cos\theta$

The mean counting rate for the multiplicity m:

$$\bar{\nu}_m = \int_0^\infty \left(\int_0^1 P(m,n,D) \frac{dF_0}{dD d\Omega} d\cos\theta \right) dD$$

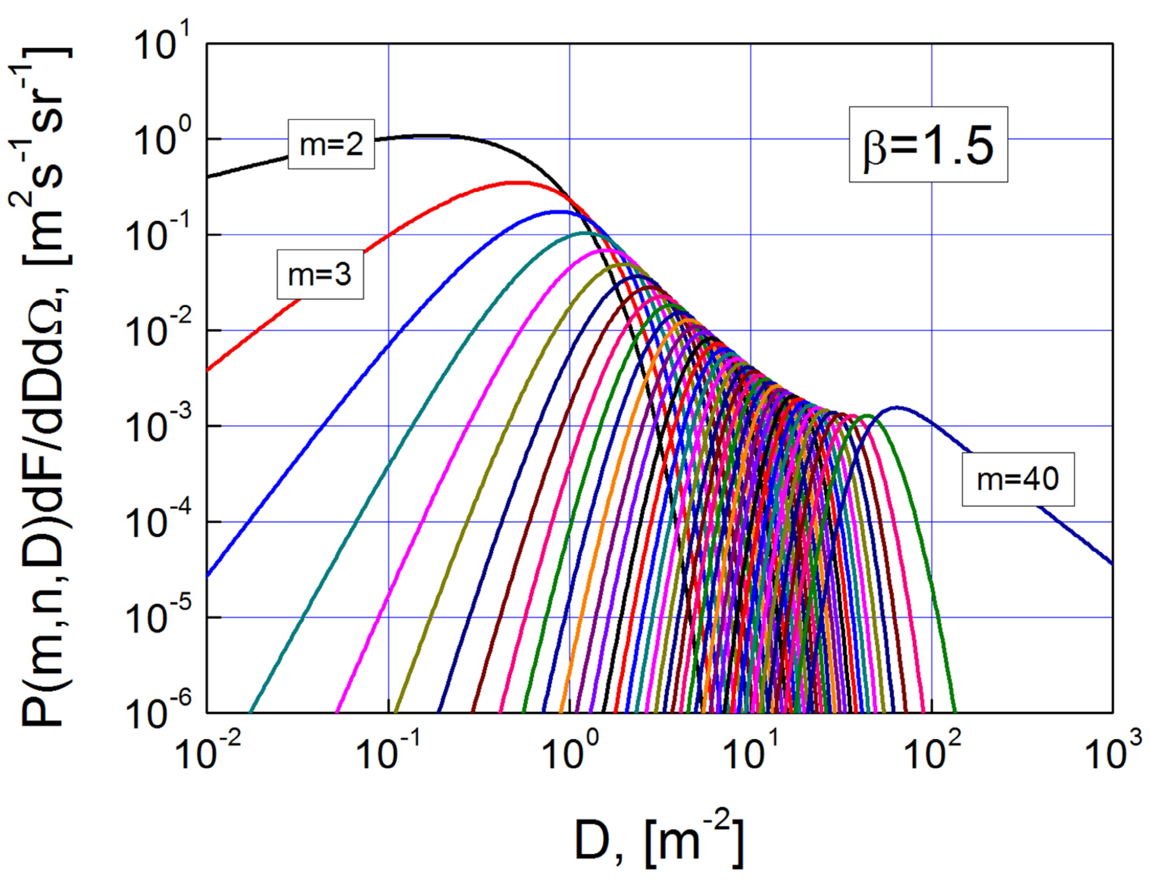
where $P(m,n,D) = C_n^m p^m (1-p)^{n-m}$

Reconstructed spectrum:

$$\frac{dF}{dD d\Omega} = \frac{\nu_{\mathrm{m}}^{\mathrm{ex}}}{\bar{\nu}_{\mathrm{m}}} (D^*/D_0)^{-(\beta+1)} f(\theta^*)$$

D* and cosθ* are mean logarithmic values.

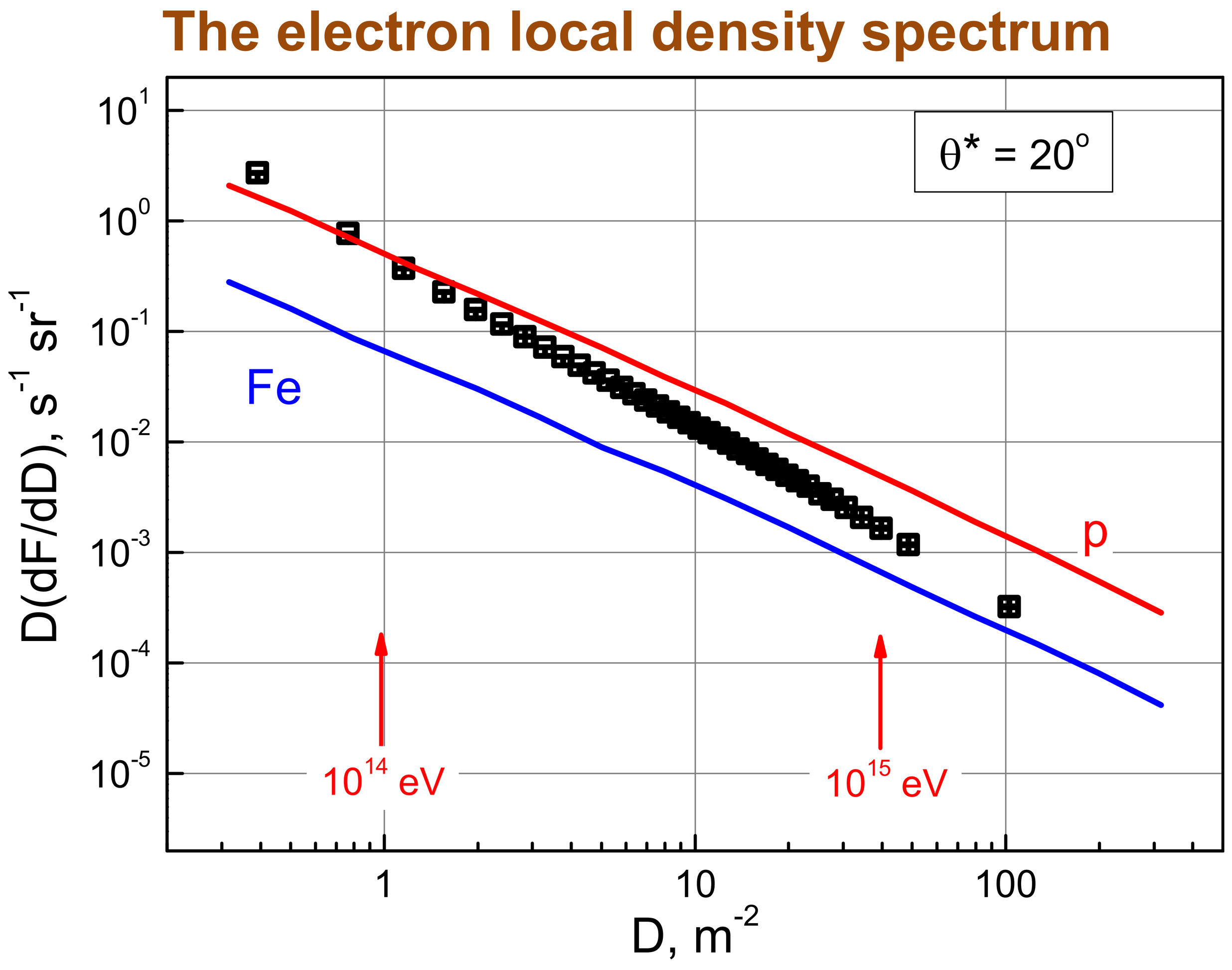
Different charged particle density contribution of to a certain multiplicity of hit counters



About 31.5 million events in top CTS plane were used for reconstructing EAS electron local density spectrum. The total "live time" of measuring is 11806 h (~492 days).

About 113 thousand events in bottom CTS plane were used for reconstructing EAS muon local density spectrum. The total "live time" of measuring is 11909 h (~496 days).

The electron local density spectrum

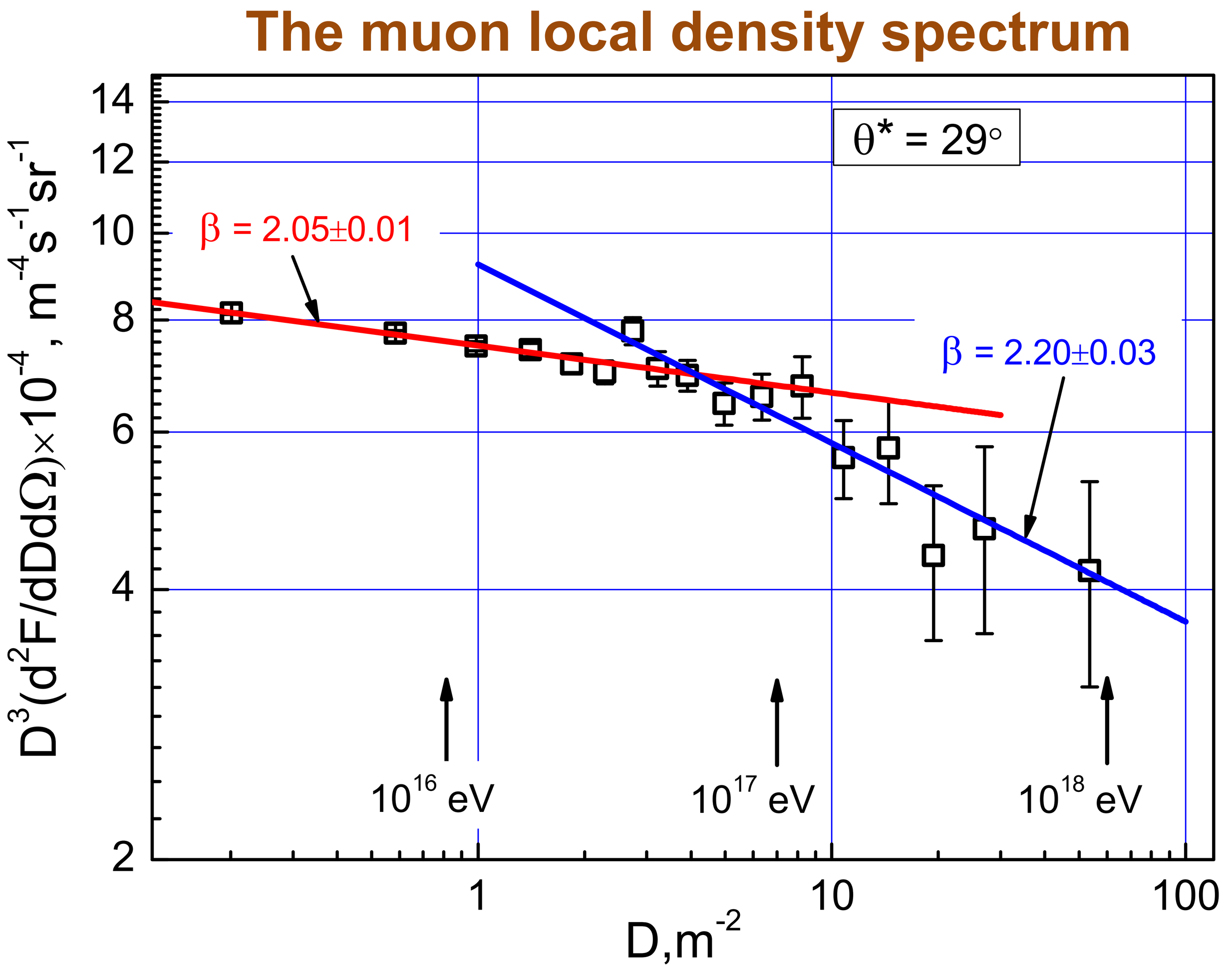


On the plot, the squares represent the spectrum reconstructed from the hit counter multiplicity in the upper plane, the red line is the calculated spectrum for the primary protons, the blue line is the calculated spectrum for the primary iron nuclei. The primary mean logarithmic energy values for protons are represented by arrows.

As of preliminary, we compare experimental results with calculations based on a simple model of the CTS setup and of the building roof and the spectrum model for primary protons and iron nuclei:

$$\frac{dN}{dE} = \begin{cases} 5.0 \times (E, \mathrm{GeV})^{-2.7}, E < E_{\mathrm{knee}} & E_{\mathrm{knee}} = 3 \times 10^6 \ \mathrm{GeV} \\ 5.0 \times (E, \mathrm{GeV})^{-2.7} (E / E_{\mathrm{knee}})^{-0.4}, E \geq E_{\mathrm{knee}}; & E = 10^3 - 3 \times 10^7 \ \mathrm{GeV} \end{cases}$$

The muon local density spectrum



On the plot, the squares represent the spectrum reconstructed from the hit counter multiplicity in the bottom plane, the red line is the fit of the density range 0.2 – 8.3 m^{-2}, the blue line is the fit in the density range 2.7 – 54 m^{-2}. Mean logarithmic primary energies are represented by arrows.

To estimate the CR energy, we used the approximate formula for the CR mean logarithmic energy as a function of local muon density:

$$\lg(E, \mathrm{GeV}) \approx 7.03 + 1.07 \lg(D, \mathrm{m^{-2}}) + 3.80 \lg(\sec\theta)$$

Conclusion

CTS setup provides the possibility for investigating EAS in the CR energy range from ~10^{14} to ~10^{15} eV due to a small size in conjunction with the measuring technique. The exponent of the local density spectrum of charged particles is close to 1.5 in the density range from 3 to 30 m^{-2}.

Due to the presence of the water absorber, there is a possibility to measure the local muon density spectrum in the CR energy range from ~10^{16} to ~10^{18} eV. The exponent value is changed for the particle densities around ~4 м$^{-2}$. The second "knee" region of the CR energy spectrum is near to 10^{17} eV. The exponent estimates are 2.05 and 2.20 respectively for two parts of the local muon density spectrum (above and below the second "knee").

CTS provides registration of electron and muon EAS components in top and bottom planes in different CR energy ranges: from ~10^{14} to ~10^{15} eV and from ~10^{16} to ~10^{18} eV, respectively.

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http://ununevod.mephi.ru/en/